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Stable Isotope Separation in Calutrons: Forty Years of Production and Distribution

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MARTIN MARIETTA ENERGY SYSTEMS, INC.
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OPERATIONS DIVISION

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ABSTRACT

The stable isotope separation program, established in 1945, has operated continually to provide enriched stable isotopes and selected radioactive isotopes, including the actinides, for use in research, medicine, and industrial applications. This report summarizes the first forty years of effort in the production and distribution of stable isotopes. Evolution of the program along with the research and development, chemical processing, and production efforts are highlighted. A total of 3.86 million separator hours has been utilized to separate 235 isotopes of 56 elements. Relative effort expended toward processing each of these elements is shown. Collection rates (mg/separator h), which vary by a factor of 20,000 from the highest to the lowest (^{205}Tl to ^{46}Ca), and the attainable isotopic purity for each isotope are presented. Policies related to isotope pricing, isotope distribution, and support for the enrichment program are discussed. Changes in government funding, coupled with large variations in sales revenue, have resulted in 7-fold pertubations in production levels.

I. INTRODUCTION

The program to separate stable isotopes using electromagnetic equipment was formulated late in 1945 by the Manhattan Engineering District and its contractor, Tennessee Eastman Corporation. This outgrowth of the wartime separation of ^{235}U was intended to provide many unique materials to government laboratories. Initial studies planned for those new materials primarily involved nuclear cross-section measurements, but program initiators also foresaw the eventual extension of government-sponsored research into broader fields. As the potential value of separated isotopes to the private sectors of industry and medicine soon became apparent, the program objective was expanded to include the worldwide distribution of enriched materials by both sales and loan programs. Forty years of efforts in the production and distribution of stable isotopes are summarized briefly in this report. Neither the actinide nor the special high-purity separations are included; their importance warrants coverage in a separate report of this type.

II. PROGRAM EVOLUTION

The first samples separated (^{63}Cu and ^{65}Cu) were allocated by the Manhattan District for irradiation in the pile of Clinton Laboratories, now Oak Ridge National Laboratory (ORNL). From this irradiation, the first positive assignment of the 2.6-h half-life nickel isotope to mass number 65 was made.[1]

The early years of the isotope separations program have been summarized by other authors.[2-5] Some delved into specific problems; all stressed productivity and the expanding distribution of the separated products. Eventually, the monopoly on the usage of these isotopes by government laboratories began to be challenged by universities and industrial organizations having government contracts. What had been an in-house production-and-use system was to become more complicated. By that time, Union Carbide Corporation (UCC) had replaced Tennessee Eastman Corporation and the Atomic Energy Commission (AEC) had been formed.

On December 26, 1947, 15 requests for loans of isotopes to non-AEC institutions and organizations were first approved and allocations were made by representatives from two organizations: Atomic Energy Commission (AEC) and Union Carbide Corporation (UCC). Formal orders from the AEC-approved users were to be submitted to UCC for processing. Specified applications of the approved isotopes were (1) cyclotron bombardment and (2) hyperfine structure studies. In January 1948, the 15 approved distributions to non-AEC users were made. Recipients were California Institute of Technology, ^{6}Li and ^{7}Li; University of Chicago, ^{6}Li and ^{7}Li; Yale University, ^{29}Si; General Electric, ^{54}Fe; University of Wisconsin, ^{64}Ni, ^{67}Zn, and ^{204}Pb; Ohio State University, ^{70}Ge, ^{74}Se, ^{76}Se, ^{92}Mo, ^{94}Mo, and ^{98}Mo. Unapproved requests from non-AEC organizations on January 31, 1948, totaled 14.

The AEC transfer charges, plus the nominal charge of \$50 per shipment to non-AEC users of stable isotopes, totaled \$70,000 on December 31, 1951, averaging ~\$10,000 per year. Approximately two-thirds of this sum was derived from charges made against transfers of material within the AEC. The fees were charged to defray clerical and shipping costs only. All fees received in 1952 totaled \$13,650. By March 31, 1954, total shipments had reached 2034, 57.1% intra-AEC and 42.9% to non-AEC users. Of the shipments to non-AEC users, 760 went to universities, with only 112 (5.5% of total) going to industrial-type users.

In the latter half of 1954, isotopes were first shipped (sold on full-cost recovery basis) to foreign users. In that 6-month interval, ^{108}Cd, ^{112}Cd, ^{69}Ga, and ^{58}Ni went to Centre Nationale de la Recherche Scientifique; ^{142}Nd, ^{144}Nd, ^{149}Sm, ^{150}Sm, and ^{154}Sm went to Atomic Energy of Canada; and ^{128}Te went to Milan Polytechnic College. In the next 6 months, isotopes went to the Federal Republic of Germany, the University of South Africa, and the Joint Establishment for Nuclear Energy Research. No domestic user could buy isotopes at any price; however, if a loan was lost, the domestic customer was charged the established sales price.

In the first half of 1956, the AEC approved the domestic sales of electromagnetically separated stable isotopes. Allocation by the AEC was no longer necessary, and arrangements for purchase or loans were now made directly with the Stable Isotope Research and Production Division of UCC. The purchase of isotopes by the domestic user was to be encouraged, but "rare and expensive" isotopes would still be loaned (to domestic users only) provided they would not be diluted or contaminated in any manner. Listed "for sale only" were the more abundant isotopes of B, Ba, Cd, Cr, Fe, Hf, Li, Nd, Ni, Pb, Sn, and Ti bearing specified enrichment. No loans were made during a 3-month transition period implementing the new sales policy. Total shipments reached 3232 on May 20, 1956. In the next 6-month period, 312 shipments were made; the ratio of sales to loans was 252/60.

Government bodies responsible for direction and management of the isotopes program at Oak Ridge were, at first, the Manhattan Engineering District, followed by the Atomic Energy Commission, the Energy Research and Development Administration (ERDA), and currently the Department of Energy (DOE). Contractors responsible for operating the program as outlined by governmental regulations were Tennessee Eastman Corporation, Union Carbide Corporation, and Martin Marietta Energy Systems, Inc. Under Tennessee Eastman and early Union Carbide management, immediate stable isotope supervision reported to Y-12 Plant management. When Union Carbide assumed contractual management of Clinton Laboratories, which then became Oak Ridge National Laboratory, supervision was assigned to ORNL management, where it has remained. Within ORNL, the stable isotope program has reported to management through the Stable Isotope Research and Production Division, the Isotopes Division, the Isotopes Development Center, the Chemical Technology Division, and the Operations Division.

On May 1, 1956, the Stable Isotope Research and Production Division was abolished, and the stable isotopes separation program became a part of the newly organized Isotopes Division of ORNL, joining together for the first time into a single group the development, the production, and the distribution functions of the radioisotope and stable isotope programs. When the Isotopes Division was formed, an established sales office at ORNL was chosen by ORNL management as a means of distributing stable isotopes, and the inventory was moved from the refinement laboratory of the separations facility to the Sales Office at ORNL.

For calendar year 1957, income from stable isotope sales and income from loans totaled \$214,940.21. This income represents an increase of 32.5% over that derived from all transactions in 1956.

At the onset of the separation program, all activities were government funded, and the materials were dispersed to only government-sponsored users. Nondestructive uses were loans; destructive or altered-abundance uses eventually became reimbursable. All shipments of each isotope were from the same separated isotope inventory. Later, sales were made to users both outside and inside the AEC-sponsored programs and cost-pricing problems were born. From the total inventory (Cross Section Pool), loans and certain sales allocations could be made. Some years later, the Cross Section Pool became the Research Materials Collection (RMC), and the sales inventory became a separate entity.

From 1947 to 1959, the effort expended in tank hours remained relatively constant. (Following a long-established custom, the term "tank hours," is used in this report to express the number of separator hours.) Initially, four separators (two alpha-48-in. radius and two beta-24-in. radius) were operated continuously, on a 24-hour-day, 7-day-week schedule, by a staff of ~85 people. On July 1, 1949, personnel were reduced by 30%, chiefly in the areas of R&D and chemistry. No reduction in tank hours was involved, and a concentrated effort was continued to maximize the number of isotopes separated per unit time to extend research rapidly into as many areas as possible. By 1959, it was evident that outside uses involving sales would eventually drain the available Cross Section Pool of isotopes if productivity were not increased.

In March 1960, production capability of the separations program increased from the four-separator operation in Building 9731 into a possible 30-separator facility in Building 9204-3. The expansion program placed 28 separators in operation on a 24-hour, 7-day schedule for several years. As inventories built up, operation dropped to a 5-day schedule. Unfortunately, funding cuts reduced the number of operating separators drastically in 1970, as discussed in Sect. V, "Production," and still further in 1983 and 1984. The sales inventory is currently being rapidly depleted, and corrective actions are indicated.

III. RESEARCH AND DEVELOPMENT

The research and development (R&D) section assumes the reader is familiar with the design and operating characteristics of the calutron. For those who are not familiar and wish to have a better understanding of the calutrons, it is suggested that they refer to Division I of the National Nuclear Energy Series (NNES I) and the references listed therewithin.

At the onset of the program, 16% of all personnel were in the R&D group, and the entire stable isotope separation program bore the official title of Isotope Development Department of the Y-12 Research and Production Division. Equipment available for use had been designed for the separation of uranium isotopes from uranium tetrachloride (UCl_4) feed; it was inevitable that changes would be required in the ion source and the receiver as other feed materials and other isotope spectra were encountered. The extent of the problems faced by the R&D group is evidenced by the the fact that personnel reduction did not occur until July 1949. At that time, the R&D staff was reduced to 14 people. In the year prior to the reduction, 28.2% of available separator time was devoted to research; in the following year, the corresponding value was 25.8%.

Funding for R&D was curtailed in the mid-1950s, but was reinstated at ~10% of operating budget, concurrent with the need to acquire larger amounts of enriched lithium isotopes. This funding level continued until 1981. There is no provision for R&D in the funding provided now to the isotope separations group.

The accomplishments of R&D effort are summarized tersely in the following statement. In most instances, a quantity of an isotope today sells for less (considering purity) than the same quantity sold for in 1954, when sales of isotopes were initiated (see Appendix A for comparison of prices).

Specific accomplishments, taken somewhat in chronological order, start with extension of the temperature range of the charge oven in the ion source and development of a universal-use receiver having standardized and interchangeable collector pockets. Arc-chamber studies followed, and these merged with oven-temperature extension to form the M-16 or larger version, M-18, ion source now used in >90% of the separation effort. Further extension of oven temperatures (>1100°C) gave rise to the electron-bombardment-heated ion source, providing an oven temperature of 2800°C. This source made possible the initial separation of the platinum-group elements.

Universal design of the receiver provided the desired reduction in construction and servicing time, but 43% of the ions monitored into pockets prior to 1957 were lost by sputtering. Redesign of individual pockets has reduced this loss to less than 20% on average and to <10% on many isotopes.

Collection of mercury isotopes, which are very volatile, was attempted first using a massive liquid-nitrogen-cooled receiver. The approach failed, and mercury isotopes were later collected in specially formed silver pockets coated on the outside with Glyptal^{tm}. The tank liner was refrigerated with alcohol cooled by a dry-ice-bath heat exchanger. The method provided ^{196}Hg at 3.3% average purity (8.4% maximum) and consumed 18,000 lb of dry ice per milligram of contained ^{196}Hg. Subsequent development of the charge-exchange receiver and collection of $^{196}Hg^+$ on a water-cooled plate, continuously subjected to vapors of Octoil S^{tm} (a vacuum pump oil), yielded 44.7% average purity ^{196}Hg without the use of dry ice. Five cubic centimeters of oil replaced tons of dry ice and increased the isotopic purity by a factor of 10. The charge-exchange receiver is useful with all low-abundance isotopes; the oil-coating technique is applicable to low-abundance, highly volatile isotopes.

Design and construction of six separators of the 255° double-focusing type grew out of the need to acquire an increase in beam dispersion between adjacent isotopes. These new separators utilized the vacuum tank of the original calutron and required no alteration in coil structure generating the magnetic field needed for their operation. One design feature unique to these separators is excessive curvature of the ion exit slit to produce a straight-line focal pattern at the collector. This feature greatly simplifies pocket fabrication and receiver assembly.

The design and construction of the sector separator, having a radial field inhomogenity of 0.8 and a deflection angle of 180°, followed successful testing of the 255° double-focusing separators. Like its predecessors, the sector separator fits into the vacuum volume of the old calutron it replaces. Existing pumps evacuate the shim region, while new high-speed diffusion pumps evacuate both the source and receiver flight tubes. Providing almost 8 times the mass dispersion of the calutron and approximately 1% of the ion output of the calutron, this separator becomes useful in high-purity separations and direct target preparation.

Beam-boundary plates now aid in the space-charge neutralization of beams as they traverse the distance from source to receiver. Initially designed for use in runs where a shorter-than-normal ion exit slit was a preferred ion-source feature, these plates now form an integral part of the liner system. Placed ~1/2 in. from the beam boundary, they provide sufficient stabilizing effect that operation can be performed at lower tank pressure and, hence, reduced ion scattering.

Both pressure reduction and beam stabilization are achieved by use of calcium vapor pumping. This development was an outgrowth of the need to combat excessive carbon tetrachloride (CCl_4) pressure present in systems where feed was being formed within the ion source by reaction of an elemental oxide in the presence of a controlled flow of CCl_4. Calcium vaporized at the rate of ~1 g/h removed unreacted CCl_4 and also provided unprecedented beam stability. Calcium pumping is now in routine use.

Horizontally positioned baffle plates have increased the gas conductance from source to pumps. Lower operating pressures resulted, as proven by a 15% increase in pumping speed from the ion exit slit, when these baffles replaced the standard baffles.

The above developments are hardware oriented and are easily recognizable, but of no less importance were the many subtle changes in power supplies required in support of research, the problems solved in providing volatile, yet anhydrous feed materials, the quantitative recovery and refinement of isotopes to chemically stable forms, the reprocessing of returned isotopes containing various degrees of contaminants, and the containment of potentially hazardous materials. In similar manner, development of outgassing and operational procedures, in-process controls, and product evaluation have all contributed to the overall separations program. Publications describing R&D, chemical processing, operations, production, and sales are listed in Appendix B. Twenty patents (see Appendix C) protect the interests of DOE in the developments generated within this program.

IV. CHEMISTRY

Experience gained during the uranium separations program had shown that separator charge materials should be anhydrous, capable of attaining ~100-μm vapor pressure in the 400-500°C temperature range, and relatively free of impurities, including adsorbed gases. As ion source ovens were altered, restrictions on the temperature-vapor pressure relationships were relaxed, but the need for anhydrous feed material is probably stressed more today than it was in the early stages of the separations program. In the initial years of the program, charge preparation chemists provided as wide a diversity of feeds as was possible, so that operation could test the performances achieved with each feed and establish a preference. In addition, charge materials were provided for pre-evaluation runs in the small-scale separator used in the charge-evaluation laboratory. Suitable feeds for elements such as rhenium, the platinum metals, and the rare earths were unknown at the time of scheduled separations, and chemical development was required. The scope of the charge preparation effort is evidenced by the fact that ~5 x 10^6 g of anhydrous, suitably volatile chemicals has been consumed by ion sources during the lifetime of the program. Most of this quantity has been directly synthesized in the charge preparation laboratory; virtually all of it has been dried and pre-outgassed at elevated temperature. As the separations program matured, the need for diversity in feed compounds decreased, and efforts to improve on charge purity (including occluded gases) intensified.

Chemical recovery and recycle of unresolved feed material have always involved collection of wash solution, storage, and disposition of hazardous materials. Complete recovery of valuable or irreplaceable feeds has always been practiced, followed by purification and a conversion back into another batch of feed (recycle operations). Silver, the platinum group, the majority of rare earths, and all pre-enriched feeds are subjected to recycle treatment. In general, the material balance per cycle through the system approaches 90%.

Isotope recovery and refinement involves removal of isotopic material from collector pockets and purification to a chemically stable form, using quantitative gravimetric techniques. The goal is a high-purity chemical product derived from a grossly contaminated matrix without loss of any of the desired isotopic component. Initial collector pockets were made of graphite or copper; later aluminum, cadmium, and silver were employed; then copper-graphite, copper-Octoil S, and copper with oxygen metered into the pocket to form oxide compounds came into use.

In addition to isotopes and pocket materials, the collected materials were found to contain small amounts of virtually all chemicals found in structural materials within the separator tank, deposited within the collector pocket as a result of ion sputtering and vaporization. From this environment, isotopes had to be recovered quantitatively. Material lost was not replaceable within a reasonable time frame.

Initial recovery and refinement generally involved extensive literature searches for gravimetric procedures, development of a plan of attack, performance of a dry recovery using the normal element, introduction of indicated procedural changes, and finally recovery and refinement of each isotope of the element. It was soon realized that graphite collector pockets were being machined from impure stock, but no vendor supplied pure graphite in the large billets required for pocket fabrication. Construction of a graphite-purification furnace alleviated the problem. Improvement in the purity of commercial graphite eventually retired this massive furnace from operation. In a similar vein, the sputtering of components of stainless steel into collector pockets was reduced by lining all baffle surfaces exposed to the beam with graphite plates.

The removal of isotopic material from the interior of a graphite pocket is generally accomplished by burning the entire pocket after the exterior surface has been cleansed by deep sanding (~1/64 in. of surface removal). If pocket construction involves massive pieces of graphite, these surfaces are scraped until all isotopic material is removed. Copper or other metallic collector pockets are generally leached with acid after the outside has been cleaned and taped. Problems with all types of collector pockets arise whenever the ion beam has sputtered sufficient material to the extent that a hole has formed in the wall of the pocket. Cross contamination is difficult to avoid, and quantitative recovery of the isotope depends strictly upon the ingenuity of the recovery chemist. One drastic approach involves a best-effort cleansing of the outside surface followed by dissolution of the pocket. The resulting solution may contain isotopes in ratios of 1/500 to 1/1000 to impurities. Special techniques must be applied in many such recoveries.

Meticulous record keeping and retention of laboratory notebooks have allowed the compilation of refinement procedures into one single volume.[6] This work is a guide only; the search for improved methods still continues.

Refinement does not mean an end to chemical responsibilities for a given isotopic enrichment. Small portions must be withdrawn for spectrographic and for mass analysis, both of preliminary and of final product. Often, conversion of an inventory compound into a suitable form for mass analysis is required. Similarly, repurification and recertification of returned loan samples represents a fair fraction of total chemical effort.

To some degree, the efficiency of chemical activities is reflected in the 1945–1955 staff level of ~22 chemists processing the isotopes from four separators, as compared with the 1980 level of approximately four chemists processing the isotopes from 16 separators. It is a further tribute that ~85% of isotopes monitored into present collector pockets are recovered and refined into an inventory product.

V. PRODUCTION

From program inception in 1945 to early in 1960, productivity was limited to that of a four-separator operation. The newness of the materials generated a ready demand, and the operation involved a number of short campaigns (series) in order to maximize choices in available research material and to develop a feel for how well existing equipment would perform over a broad range of operating conditions. In a "first time" separation, equipment was pushed to achieve a maximum throughput of ion current, then output requirements were relaxed in favor of stable operating conditions. Troublesome features were noted, to facilitate equipment changes to be incorporated into the next separation of that element. Thus, the learning process continued. Feed materials were changed frequently, and early preference was given to halide compounds because of experience with uranium. Later, other feeds became more readily acceptable[7] as the temperature range of ion sources was extended and contaminating mechanisms were better understood. By 1960, all elements having stable isotopes (the rare gases excepted) had been processed at least once. Iron had been processed 20 times.

During the first 8½ years of operation, when there were no outright sales of separated isotopes, each isotope was loaned and all isotopes were wanted. Demand often outstripped supply, and the advent of sales increased the problem. Increased productivity from R&D effort and equipment modification could not keep pace with demand for isotopes. In 1959, expansion of productivity was authorized; a 28-separator operation ensued from March 1960 until about 1970. Sales by now had become a significant factor in the distribution of isotopic products. Starting with an accounting change in FY 1964 (discussed in Sect. VII, "Effect of Pricing Practices on Inventory Maintenance"), the income from sales eventually dictated the level of operations possible on a yearly basis. Based on available income (not demand), the operational level was reduced to 20, then 16 separators in about 1970 and maintained at 16 until about 1982. In 1983, the level averaged 8 separators (16 separators for 6 months), and in 1984 the level dropped to 4 separators (8 separators for 6 months).

During the 40-year lifetime of the program, 3.86 million tank hours (separator hours) have been allocated to the separation of stable isotopes. From a beginning in which all isotopes were virtually equal in importance, certain preferences have developed. Calcium is still a strong leader (the demand is nearly 100 times greater than antimony); requirements for mercury and molybdenum are currently falling off; thallium, tellurium, and zinc are rising; the remainder are approximately maintaining the status quo. Iron has been processed 27 times, calcium 24; in comparison, dysprosium, europium, lanthanum, lutetium, and osmium have each been processed only three times. Vanadium was last separated in 1948. An abnormally large number of elements were separated during 1983-84, when tank hours were so low. This was accomplished by separating the isotopes of those elements having compatible magnetic field requirements simultaneously in the same magnetic field. This action represents a reversal of 1947 operational philosophy: Make numerous short separations to provide needed material, even though such short campaigns are not a cost-effective approach to isotope separation.

Including the operational aberration in 1983-84, the average time lapse between repeat separations of the same element ranges from 1.5 years for iron to 13.3 years for osmium and some rare earths. The areas of separation effort summarized above are detailed in Table 1 and Figs. 1-5. The figures show the division of effort into four groups, each containing 14 elements, and the subdivision of effort within each group.

The collection rate of isotopes in terms of milligrams per separator hour varies widely between elements and according to natural abundances within the feed. There is also some variation in collection rate between separation campaigns using the same equipment and feed. Because of such variations, a representative campaign for each element has been chosen as a "reference" which should be duplicated in future work. The collection rates achieved for each isotope in such a campaign are listed in Tables 2 and 3. In Table 3, the isotopes are arranged in order of increasing productivity (mg/tank hour). It is interesting to note that on the mg/tank hour basis, the spread in collection rate from highest to lowest (^{205}Tl to ^{46}Ca) is in the ratio of 20,000 to 1; whereas, on a μmol/tank hour basis, the ratio of highest to lowest (^{58}Ni to ^{46}Ca) is 14,000 to 1. On both the mg/tank hour and the μmol/tank hour basis, the five most difficult-to-separate isotopes are ^{46}Ca, ^{40}K, ^{36}S, ^{184}Os, and ^{156}Dy.

VI. DISTRIBUTION BY SALES

Isotope sales, like production, has undergone several changes in its 30-year lifetime. Initial sales (to foreign users only) were highly dependent on availability and upon AEC approval of the intended use. Subsequent sales to domestic users did not require approval by the AEC, but the problem of availability still existed. Many orders could not be filled until another separation had been completed. For that reason, the present data on sales are chosen to cover only the last 15-year interval (1970–1984). The starting point, 1970, coincides with a 10-year buildup of the inventory by high-level (28-separator) operation. Thus, in 1970, there were virtually no zero-inventory isotopes. From customer and shipment reports,[8–12] sales data have been grouped into three intervals, each showing 5-year averages of annual quantities of isotopes sold (Table 4, and shown graphically in Appendix D). These quantities were distributed between domestic, foreign, and project-sponsored customers; these distributions and the income associated with each type of customer are shown for each year in Table 5, and the annual variation of revenue is shown in Fig. 6. The grand total of all sales quantities and revenues for each calendar year of 1973–1984 is shown in Fig. 7. The quantity in milligrams sold to all sources rose from 872 x 10^3 mg in 1970 to a plateau of ~1300 x 10^3 beginning in 1972 and continuing to 1979. From 1979 to 1981, sales rose to a peak of 2020 x 10^3 mg. Thereafter, sales declined to 1145 x 10^3 mg in 1984. Income exhibited a similar trend, starting at $1.08 x 10^6, peaking at $3.74 x 10^6, and falling to $2.63 x 10^6 in 1984. Total quantities sold have declined steadily since 1981, with a 70% drop in sales to domestic (principally medical usage) customers. Sales to both foreign and project users increased during the 1981–1984 interval. Comparison of quantity and income shows the relative increase in the average cost of producing isotopes during the 15-year period ($1.24/mg in 1970 vs $2.30/mg in 1984).

As of December 31, 1984, the isotopes listed in Table 6 carried a zero balance in the sales inventory. Under approved circumstances, loans from the separate loan inventory (the RMC) may be made to the sales inventory, with replacement indicated on an equal cost basis. Thus, sale of 20-year-old RMC stock replaced at current cost is a favor extended to the customer and a millstone to the separations program, which absorbs the cost difference. The number and value of zero-inventory isotopes are expected to increase if present operational and sales levels continue.

The RMC now contains more than 29 x 10^6 mg of separated isotopes. This quantity is almost 1.5 times the amount sold during the past 15 years. RMC material on active loan each year approaches 8 x 10^6 mg — almost 40% of the total sales volume for 1970–1984, or six times the average sales volume per year. Some 315,000 mg of RMC stock has been loaned to the sales inventory and is to be replaced at cost by isotopes to be separated at a later date. The present sales inventory (12/31/84) contains 3.13 x 10^6 mg, just over an average 2-year supply. Sixty-three isotopes have 0 to <6-month inventory balance.

Over the years, certain isotopes have established themselves as good sellers; others have shown spurts of activity. In Table 7, all isotopes having produced an income of $\geq$\$20,000/year during any year of the 1970-1984 period are listed, along with their annual income for each year. Even casual study of this data shows the volatility of sales and the difficulty of projecting demands for even the "best selling" isotopes. If the past is difficult to explain, how is the future accurately predictable? More than 50% of the operating budget comes from anticipated sales within the operational year. There can be no budget overruns; profits cannot be carried over into another year. The only avenue open to operations under present conditions is one of conservatism and decline.

VII. EFFECT OF PRICING PRACTICES ON INVENTORY MAINTENANCE

It is an interesting exercise to recreate the thoughts generated by those establishing the initial pricing system for isotopes. Two criteria were to be met: (1) full-cost recovery and (2) fairness in the allocation of costs. A determination of the total cost of separating all the isotopes of a given element was quite straightforward. It was the allocation of cost to a specific isotope, or to a batch of a specific isotope, that generated choices in judgment. Established premises at the time were few: production was in direct ratio to natural abundance; there were generally two or more batches of each isotope, each having a different degree of enrichment; all batches were useful, but probably not to the same extent; higher-enrichment material would generally be preferred over lower-purity material; and sales would be only to foreign users unless a domestic user lost or contaminated a loaned sample. Eventually, a system was agreed upon. Total separation cost for the element would be divided equally between the isotopes of the element; thus, the cost per milligram of an abundant isotope was less than that of a less abundant isotope. To adjust for differences in purity levels, an "enrichment squared" term was applied, so that the unit cost of highly enriched material was greater than that of material having a lesser enrichment. In adding new material to an existing inventory, costs of existing and new material would be weight-averaged, so that the price of the new inventory could reflect advances achieved through process improvements. Everything looked fine, and a price list was published in 1954.[13] Material would be removed from the bottle previously assigned to the Cross Section Pool and would be shipped to the customer (foreign). Income would be credited to an appropriate account, and that amount would be funneled back into the government coffers. The isotopes separation program was operating with a known and guaranteed annual budget, but it was beginning also to generate a significant amount of revenue. Domestic sales were approved in 1956. Sales grew, and a separate sales inventory was established.

From its inception in 1945 until the beginning of FY 1964, the stable isotope separation program had been totally funded by government agencies, with revenues from handling and sales of isotopes returning to the government. During each year, the operating budget was known precisely upon adoption of the federal budget. Fluctuations in sales revenues from year to year exerted no influence on the operation of that year. Beginning in FY 1964, the operating budget has been comprised of a known government-funded amount plus the income derived from the year's sales. Sales income normally exceeds government funding, and the operation level is now determined in effect by actual fiscal year sales income and not by projected or "average experience" demands. Programmatic spending levels are based on a known income from government sponsors and an uncertain income from sales, which must be received during the year in which it is spent and which cannot be predicted dependably. Sales revenue generates only recovery of full cost experienced at the time of production. Sales from past inventory at the old production cost in an inflationary economy do not generate sufficient revenue to support present-day replacement of isotopes sold. The low-volume sales of some inventoried isotopes and the presence of "surplus" isotopes further complicate the problem.

The expansion program initiated in 1960 to increase inventory levels and perhaps introduce more income and stability into sales did not alleviate the overall problem. During this time, it became clearer and clearer that not all isotopes were equally desirable. Fortunately, those isotopes not selling well could, at first, be utilized effectively by adding them to the Cross Section Pool (now the RMC), which is a separate inventory maintained for loans. Eventually, this pool became saturated with certain isotopes, and "surplus" isotopes came into being. The extent of this problem is evidenced in the next two tables. Table 8 lists total isotope sales (1970-1984) and compares them in units of percent of production capability. As an example, in the past 15 years, only 9% of the ^{137}Ba produced has been sold. In Table 9, the inventory of all isotopes in stock on December 31, 1984, is listed. The tabulation also contains average annual sales for 1980-84, tank-hour replacement time, and surpluses which will be generated during the time needed to collect the most time-consuming isotopes. Differences in relative tank-hour requirements shown in Tables 8 and 9 are indicative of changes in the relative amounts of isotopes sold over the 15-year period and those sold during the last 5 years of the period.

Inventory buildup started in 1960 and continued until about 1970. Costs of unit production during that time were lowered, due to the efficiencies of R&D improvements and of larger-scale operation. The effect of these lowered costs and the addition of large quantities into the inventory reduced sales prices significantly. In fact, this reduction in sales prices carries over into 1984. Comparison of initial prices with 1984 prices is shown in Appendix A. Some current prices are less by a factor of 2 to 10 than they were at the beginning of the sales program. The sale of a milligram of this material will not allow replacement of a like milligram, because of escalating production costs. Sales income certainly does not match replacement cost.

To cope with the surplus isotope problem, a revision in the pricing structure was approved: Quantities of isotopes which would provide a 3-year inventory are projected; the total cost for the separation is then prorated among isotopes according to the total tank hours required to fulfill all the 3-year inventory requirements; the enrichment-squared correction term and the averaging of existing-inventory and new-inventory-addition costs still applies. This method helped eliminate tying up dollars in an inventory that was not moving, but it also introduced other features. It allowed little room for error in projected use, and it introduced a cost fluctuation totally dependent on the inventory level of other isotopes of the element. If other isotopes fail to sell, all cost of the next separation is charged to the isotope being replenished. Sales income is still below replacement cost, and customers are confused by seemingly unpredictable price fluctuations.

During the period 1970–1974, the quantities sold required a 23-separator operation to replenish only the sales inventory (RMC additions are ignored), but there were only 16 separators in operation as discussed in Sect. V, "Production." During a similar 5-year interval, 1980–1984, sales required 15 separators to supply the sales inventory depletion, but in 1984, the equivalent of only 4 separators were in operation. Again, only distributions from the sales inventory are considered. If sales are to remain the major source of isotope separation income, some means of adjusting sales income to match replacement cost is essential. Also, a smoothing out of cost is indicated to promote customer acceptance and understanding of the process. From an operational viewpoint, the establishment of known funding at the beginning of each year must be a major goal.

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Table 1. Summary of separation efforts, 1945-1984

Element	Percent of total tank h	Number of separation campaigns	Average time lapse between campaigns (year)	Year of last separation
Calcium	11.79	24	1.67	1982
Iron	8.32	27	1.48	1983
Mercury	4.78	13	3.08	1982
Molybdenum	4.54	10	4.00	1972
Tin	4.24	13	3.08	1975
Silicon	4.15	10	4.00	1983
Nickel	3.97	17	2.35	1978
Thallium	3.82	8	5.00	1983
Tellurium	3.66	13	3.08	1982
Sulfur	3.29	7	5.71	1968
Strontium	3.21	9	4.44	1971
Ytterbium	3.18	6	6.67	1981
Lead	3.13	22	1.84	1981
Zinc	2.82	15	2.67	1984
Tungsten	2.41	7	5.71	1965
Zirconium	2.37	8	5.00	1973
Selenium	2.21	12	3.33	1976
Gadolinium	2.08	10	4.00	1970
Chromium	1.90	13	3.08	1983
Cadmium	1.64	13	3.08	1983
Cerium	1.58	7	5.71	1970
Neodymium	1.53	7	5.71	1969
Magnesium	1.38	10	4.00	1983
Titanium	1.23	8	5.00	1983
Copper	1.19	8	5.00	1983
Potassium	1.18	15	2.67	1968
Chlorine	1.09	5	8.00	1976
Barium	1.06	7	5.71	1968
Erbium	1.04	5	8.00	1968

Table 1 (continued)

Element	Percent of total tank h	Number of separation campaigns	Average time lapse between campaigns (year)	Year of last separation
Samarium	1.03	9	4.44	1967
Hafnium	1.02	6	6.67	1971
Lithium	0.93	17	2.35	1956
Dysprosium	0.84	3	13.33	1968
Rubidium	0.81	7	5.71	1973
Germanium	0.79	7	5.71	1983
Tantalum	0.75	4	10.00	1962
Bromine	0.59	5	8.00	1969
Palladium	0.54	4	10.00	1983
Europium	0.38	3	13.33	1964
Gallium	0.38	4	10.00	1970
Silver	0.32	7	5.71	1967
Ruthenium	0.31	5	8.00	1983
Osmium	0.29	3	13.33	1983
Platinum	0.27	4	10.00	1983
Carbon	0.27	6	6.67	1957
Lutetium	0.25	3	13.33	1961
Boron	0.24	8	5.00	1969
Lanthanum	0.22	3	13.33	1961
Iridium	0.21	5	8.00	1983
Indium	0.18	8	5.00	1959
Rhenium	0.17	5	8.00	1971
Vanadium	0.15	3	13.33	1958
Antimony	0.14	4	10.00	1967
Nitrogen	0.06	1	40.00	1955
Beryllium	0.03	2	20.00	1949
Bismuth	0.02	1	40.00	1959
Oxygen	0.01	1	40.00	1948

Table 2. Elemental listing of generally achieved purity and collection rates of isotopes[a]

Isotope	Isotopic composition (at. %) Natural	Isotopic composition (at. %) Enriched	Series	Total product to receiver (mg/image h)	Image (%)	Retention (%)	Pocket recovery (mg/tank h)	Collection rate (mg/tank h) Collector I	Collection rate (mg/tank h) Collector II
Antimony-121	57.25	>99	IC	147.7	74.0	44.7	28.0	28.0	
Antimony-123	42.75	>99				63.0	29.4	29.4	
Barium-130	0.101	35–60	OJ	97.8	80.4	107.0	0.085	0.085	0.085
Barium-132	0.097	20–50				180.0	0.137	0.137	0.137
Barium-134	2.42	80–85				108.0	2.06	2.06	0
Barium-135	6.59	>93				79.3	4.11	0	4.11
Barium-136	7.81	>92				132.0	8.11	8.11	0
Barium-137	11.32	>89				115.0	10.2	0	10.2
Barium-138	71.66	>99				80.0	45.1	45.1	0
Bromine-79	50.52	>98	OR	46.0	63.9	71.7	10.6	10.6	
Bromine-81	49.48	>98				64.0	9.31	9.31	
Cadmium-106	1.215	80–91	PQ	135.4	85.2	79.5	1.11	1.11	1.11
Cadmium-108	0.875	>69				99.9	1.01	1.01	1.01
Cadmium-110	12.39	>96				70.0	10.0	10.0	0
Cadmium-111	12.75	>95				64.0	9.41	0	9.41
Cadmium-112	24.07	>97				67.4	18.7	18.7	0
Cadmium-113	12.26	>86				66.0	9.34	0	9.34
Cadmium-114	28.86	>98				62.5	20.8	20.8	0
Cadmium-116	7.57	>98				64.0	5.59	5.59	5.59

Table 2 (continued)

Isotope	Isotopic composition (at. %)		Series	Total product to receiver (mg/image h)	Image (%)	Retention (%)	Pocket recovery (mg/tank h)	Collection rate (mg/tank h)	
	Natural	Enriched						Collector I	Collector II
Calcium-40	96.97	>99.9	NI & NX	142.8	79.3	50.0	54.9	54.9	
Calcium-42	0.64	>93				60.4	0.438	0.438	
Calcium-43	0.145	>79				67.2	0.110	0.110	
Calcium-44	2.06	>98.5				71.7	1.67	1.67	
Calcium-46	0.0033	>43				146.5	0.0055	0.0055	
Calcium-48	0.185	>97				74.5	0.156	0.156	
Cerium-136	0.193	35–50	OP	50.1	64.5	158.0	0.099	0.099	
Cerium-138	0.25	>25				325.0	0.263	0.263	
Cerium-140	88.48	>99.5				93.1	26.6	26.6	
Cerium-142	11.07	>92				83.2	2.98	2.98	
Chlorine-35	75.53	>99	QC	31.3	60.2	74.7	10.6	10.6	
Chlorine-37	24.47	>98				62.0	2.86	2.86	
Chromium-50	4.31	>95	OO	83.2	73.8	84.4	2.23	2.23	
Chromium-52	83.76	>99.7				90.3	46.4	46.4	
Chromium-53	9.55	>96				87.0	5.10	5.10	
Chromium-54	2.38	>94				63.3	0.925	0.925	
Copper-63	69.1	>99.8	NR	123.9	86.3	80.0	59.1	59.1	
Copper-65	30.9	>99.6				78.0	25.8	25.8	

Table 2 (continued)

Isotope	Isotopic composition (at. %)		Series	Total product to receiver (mg/innage h)	Innage (%)	Retention (%)	Pocket recovery (mg/tank h)	Collection rate (mg/tank h)	
	Natural	Enriched						Collector I	Collector II
Dysprosium-156	0.052	21–34	OB[b]	73.9	77.4	115.0	0.034	0.034	0.034
Dysprosium-158	0.090	>20				103.0	0.053	0.053	0.053
Dysprosium-160	2.294	69–85				125.0	1.64	1.64	0
Dysprosium-161	18.88	90–96				104.0	11.2	0	11.2
Dysprosium-162	25.53	92–86				101.0	14.7	14.7	0
Dysprosium-163	24.97	93–97				88.4	12.6	0	12.6
Dysprosium-164	28.18	>98				87.0	14.0	14.0	0
Erbium-162	0.136	>27	OG[b]	76.7	77.9	214.0	0.174	0.174	0.174
Erbium-164	1.56	>73				101.0	0.941	0.941	0.941
Erbium-166	33.41	>96				95.1	19.0	19.0	0
Erbium-167	22.94	>91				97.6	13.4	0	13.4
Erbium-168	27.07	>95				93.0	15.0	15.0	0
Erbium-170	14.88	>95				94.2	8.38	8.38	8.38
Europium-151	47.77	>92	MO	60.4	70.6	92.0	18.7	18.7	
Europium-153	52.23	94–98				83.1	18.5	18.5	
Gadolinium-152	0.20	32–51	OY[c]	66.2	71.3	176.0	0.166	0.166	0.166
Gadolinium-154	2.15	>66				139.0	1.41	1.41	0
Gadolinium-155	14.73	>90				67.8	4.71	0	4.71

Table 2 (continued)

Isotope	Isotopic composition (at. %)		Series	Total product to receiver (mg/innage h)	Innage (%)	Retention (%)	Pocket recovery (mg/tank h)	Collection rate (mg/tank h)	
	Natural	Enriched						Collector I	Collector II
Gadolinium-156	20.47	93-89				70.0	6.76	6.76	0
Gadolinium-157	15.86	>90				91.8	6.87	0	6.87
Gadolinium-158	24.87	>95				70.0	8.22	8.22	0
Gadolinium-160	21.90	95-98				81.2	8.39	8.39	8.39
Gallium-69	60.20	>99	PB	67.6	82.6	72.0	24.2	24.2	
Gallium-71	39.80	>99				59.7	13.3	13.3	
Germanium-70	20.55	>98	QD	55.5	89.2	63.4	6.45	6.45	
Germanium-72	27.37	>97				76.4	10.4	10.4	
Germanium-73	7.67	>94				66.6	2.53	2.53	
Germanium-74	36.74	>98				74.6	13.6	13.6	
Germanium-76	7.67	>92				50.0	1.90	1.90	
Hafnium-174	0.18	7-19	PD[c]	45.0	71.3	98.5	0.057	0.057	0.057
Hafnium-176	5.15	64-72				44.9	0.742	0.742	0
Hafnium-177	18.39	86-91				65.0	3.83	0	3.83
Hafnium-178	27.08	91-94				81.2	7.05	7.05	0
Hafnium-179	13.78	81-87				81.3	3.60	0	3.60
Hafnium-180	35.44	>93				64.7	7.36	7.36	0

Table 2 (continued)

Isotope	Isotopic composition (at. %) Natural	Enriched	Series	Total product to receiver (mg/innage h)	Innage (%)	Retention (%)	Pocket recovery (mg/tank h)	Collection rate (mg/tank h) Collector I	Collector II
Indium-113	4.23	>96	JO	73.1	90.1	82.2	2.29	2.29	
Indium-115	95.77	>99.99				88.1	55.6	55.6	
Iridium-191	37.30	98.17	RD	56.7	49.2	83.8	8.72	8.72	
Iridium-193	62.70	99.45				99.6	17.4	17.4	
Iron-54	5.84	>96	QG	96.9	80.0	81.1	3.67	3.67	
Iron-56	91.68	>99.6				97.6	69.4	69.4	
iron-57	2.17	86-90				101.1	1.70	1.70	
Iron-58	0.31	65-76				97.8	0.235	0.235	
Lanthanum-138	0.089	>7	LC	44.8	82.8	1,069.0	0.353	0.353	
Lanthanum-139	99.911	99.99				80.0	29.7	29.7	
Lead-204	1.48	>70	NH	143.3	91.5	108.7	2.11	2.11	2.11
Lead-206	23.6	>99				85.0	26.3	26.3	0
Lead-207	22.6	>92				89.0	26.4	0	26.4
Lead-208	52.3	>98				89.2	61.2	61.2	0
Lutetium-175	97.40	>99.9	KS	66.0	76.8	89.5	44.2	44.2	
Lutetium-176	2.60	70-75				88.2	1.16	1.16	

Table 2 (continued)

Isotope	Isotopic composition (at. %)		Series	Total product to receiver (mg/innage h)	Innage (%)	Retention (%)	Pocket recovery (mg/tank h)	Collection rate (mg/tank h)	
	Natural	Enriched						Collector I	Collector II
Magnesium-24	78.60	>99.9	OD	64.8	78.0	79.0	31.4	31.4	
Magnesium-25	10.11	>97				87.8	4.49	4.49	
Magnesium-26	11.29	>99				85.4	4.87	4.87	
Mercury-196	0.15	31-48	NW & ON	35.2	65.6	195.0	0.068	0.068	0
Mercury-198	10.02	85-96				18.0	0.416	0	0.416
Mercury-199	16.84	85-91				30.0	1.16	1.16	0
Mercury-200	23.13	>95				32.6	1.74	0	1.74
Mercury-201	13.22	>92				33.5	1.02	1.02	0
Mercury-202	29.80	>96				30.0	2.06	0	2.06
Mercury-204	6.85	90-98				30.0	0.475	0.475	0
Molybdenum-92	15.86	>97	PK	142.3	76.0	89.0	15.3	15.3	
Molybdenum-94	9.12	>91				101.5	10.0	10.0	
Molybdenum-95	15.70	>96				91.2	15.5	15.5	
Molybdenum-96	16.50	>96				100.7	18.0	18.0	
Molybdenum-97	9.45	>92				92.1	9.41	9.41	
Molybdenum-98	23.75	>96				88.4	22.7	22.7	
Molybdenum-100	9.62	>97				81.9	8.52	8.52	

Table 2 (continued)

Isotope	Isotopic composition (at. %)		Series	Total product to receiver (mg/image h)	Image (%)	Retention (%)	Pocket recovery (mg/tank h)	Collection rate (mg/tank h)	
	Natural	Enriched						Collector I	Collector II
Neodymium-142	27.11	>92	OU[b]	72.6	74.8	89.4	13.2	13.2	0
Neodymium-143	12.17	>91				95.3	6.30	0	6.30
Neodymium-144	23.85	>97				91.4	11.8	11.8	0
Neodymium-145	8.30	>89				99.2	4.47	0	4.47
Neodymium-146	17.22	>97				88.8	8.30	8.30	0
Neodymium-148	5.73	>94				93.1	2.90	2.90	2.90
Neodymium-150	5.62	>96				84.0	2.56	2.56	2.56
Nickel-58	67.76	>99.9	QN[d]	256.3	66.8	84.0	97.5	97.5	
Nickel-60	26.16	>99				91.5	41.0	41.0	
Nickel-61	1.25	88-93				79.9	1.71	1.71	
Nickel-62	3.66	>96				84.9	5.32	5.32	
Nickel-64	1.16	92-96				65.0	1.29	1.29	
Osmium-184	0.018	5.45	RB	83.0	32.9	476.0	0.023	0.023	0.023
Osmium-186	1.59	>61				46.7	0.203	0.203	0
Osmium-187	1.64	>70				102.0	0.457	0	0.457
Osmium-188	13.30	>94				64.8	2.35	2.35	0
Osmium-189	16.10	>94				65.0	2.86	0	2.86
Osmium-190	26.40	>95				76.2	5.49	5.49	0
Osmium-192	41.0	>95				64.1	7.18	7.18	7.18

Table 2 (continued)

Isotope	Isotopic composition (at. %)		Series	Total product to receiver (mg/innage h)	Innage (%)	Retention (%)	Pocket recovery (mg/tank h)	Collection rate (mg/tank h)	
	Natural	Enriched						Collector I	Collector II
Palladium-102	0.96	>69	PR	90.2	67.8	82.0	0.481	0.481	0.481
Palladium-104	10.97	>95				78.8	5.28	5.28	0
Palladium-105	22.23	>97				73.2	9.95	0	9.95
Palladium-106	27.33	>98				71.8	12.0	12.0	0
Palladium-108	26.71	>98				78.8	12.9	12.9	12.9
Palladium-110	11.81	>96				73.0	5.27	5.27	5.27
Platinum-190	0.012	>4	RC	71.3	51.8	1,097.0	0.049	0.049	0.049
Platinum-192	0.78	>57				79.8	0.230	0.230	0.230
Platinum-194	32.80	>97				95.1	11.5	11.5	0
Platinum-195	33.70	>97				86.4	10.7	0	10.7
Platinum-196	25.40	>97				87.6	8.22	8.22	0
Platinum-198	7.23	>95				79.8	2.13	2.13	2.13
Potassium-39	93.08	>99.9	KI	28.5	85.2	65.3	14.8	14.8	
Potassium-40	0.0119	78-87				277.0	0.008	0.008	
Potassium-41	6.91	>98				48.9	0.820	0.820	
Rhenium-185	37.07	>96	OS	92.1	68.0	73.5	17.1	17.1	
Rhenium-187	62.93	>99.2				81.3	32.0	32.0	
Rubidium-85	72.15	>99.7	PP	67.5	85.2	73.7	30.6	30.6	
Rubidium-87	27.85	98				79.9	12.8	12.8	

Table 2 (continued)

Isotope	Isotopic composition (at. %)		Series	Total product to receiver (mg/innage h)	Innage (%)	Retention (%)	Pocket recovery (mg/tank h)	Collection rate (mg/tank h)	
	Natural	Enriched						Collector I	Collector II
Ruthenium-96	5.47	98	RH	41.0	44.2	66.5	0.659	0.659	
Ruthenium-98	1.84	>89				62.9	0.201	0.201	
Ruthenium-99	12.77	>98				70.7	1.64	1.64	
Ruthenium-100	12.56	>97				65.8	1.50	1.50	
Ruthenium-101	17.10	>97				60.2	1.87	1.87	
Ruthenium-102	31.70	>99				55.3	3.18	3.18	
Ruthenium-104	18.56	>99				70.3	2.37	2.37	
Samarium-144	3.16	85.96	NU[b]	118.3	77.2	95.5	2.76	2.76	2.76
Samarium-147	15.07	>98				92.8	12.8	0	12.8
Samarium-148	11.27	>96				98.2	10.1	10.1	0
Samarium-149	13.84	>97				90.3	11.4	0	11.4
Samarium-150	7.47	>95				90.2	6.15	6.15	0
Samarium-152	26.63	>98				98.9	24.1	24.1	24.1
Samarium-154	22.53	>98				91.2	18.8	18.8	18.8
Selenium-74	0.87	55–77	PH	31.5	88.8	49.5	0.120	0.120	
Selenium-76	9.02	>96				89.8	2.27	2.27	
Selenium-77	7.58	91–94				93.4	1.98	1.98	
Selenium-78	23.52	>97				89.3	5.87	5.87	
Selenium-80	49.82	>99				94.7	13.2	13.2	
Selenium-82	9.19	>96				71.3	1.83	1.83	

Table 2 (continued)

Isotope	Isotopic composition (at. %) Natural	Enriched	Series	Total product to receiver (mg/innage h)	Innage (%)	Retention (%)	Pocket recovery (mg/tank h)	Collection rate (mg/tank h) Collector I	Collector II
Silicon-28	92.27	>99.8	LW	62.6	78.0	77.8	35.1	35.1	
Silicon-29	4.68	>95				57.6	1.32	1.32	
Silicon-30	3.05	>94				61.8	0.920	0.920	
Silver-107	51.35	>98	NP	76.8	80.1	72.3	22.8	22.8	
Silver-109	48.65	>99				70.8	21.2	21.2	
Strontium-84	0.56	>80	MS	142.0	80.1	83.8	0.534	0.534	
Strontium-86	9.86	>95				93.7	10.5	10.5	
Strontium-87	7.02	87–93				93.1	7.43	7.43	
Strontium-88	82.56	>99.8				84.0	78.9	78.9	
Sulfur-32	95.06	>99.8	NV	87.3	67.2	85.7	47.8	47.8	
Sulfur-33	0.74	48–90				40.0	0.174	0.174	
Sulfur-34	4.18	94–98				62.0	1.52	1.52	
Sulfur-36	0.016	15–35				10.0	0.001	0.001	
Tantalum-180	0.012	4.1	KX	65.7	76.5	40,506.0	2.44	2.44	
Tellurium-120	0.089	>51	QX[c]	133.7	79.5	85.6	0.081	0.081	0.081
Tellurium-122	2.46	>96				58.1	1.52	0	1.52
Tellurium-123	0.87	76–89				74.8	0.692	0.692	0
Tellurium-124	4.61	94–97				83.7	4.10	0	4.10

Table 2 (continued)

Isotope	Isotopic composition (at. %)		Series	Total product to receiver (mg/innage h)	Innage (%)	Retention (%)	Pocket recovery (mg/tank h)	Collection rate (mg/tank h)	
	Natural	Enriched						Collector I	Collector II
Tellurium-125	6.99	>95				96.6	7.18	7.18	0
Tellurium-126	18.71	>98				65.4	13.0	0	13.0
Tellurium-128	31.79	>99				77.8	26.3	26.3	26.3
Tellurium-130	34.49	>99				69.8	25.6	25.6	25.6
Thallium-203	29.50	>95	QW	222.6	97.4	74.0	47.3	47.3	
Thallium-205	70.50	>98				72.0	110.0	110.0	
Tin-112	0.95	68-80	OT	97.4	79.2	71.0	0.520	0.520	0.520
Tin-114	0.65	>61				68.4	0.343	0.343	0
Tin-115	0.34	>32				91.1	0.239	0	0.239
Tin-116	14.24	>95				85.0	9.34	9.34	0
Tin-117	7.57	>89				94.3	5.51	0	5.51
Tin-118	24.01	>97				81.2	15.0	15.0	0
Tin-119	8.58	>84				84.3	5.58	0	5.58
Tin-120	32.97	>98				93.5	23.8	23.8	0
Tin-122	4.71	>92				79.2	2.88	2.88	2.88
Tin-124	5.98	>94				77.2	3.56	3.56	3.56
Titanium-46	7.98	>81	MN	77.5	87.5	72.2	3.89	3.89	
Titanium-47	7.75	>80				72.4	3.81	3.81	
Titanium-48	73.45	>99				75.0	37.4	37.4	

Table 2 (continued)

Isotope	Isotopic composition (at. %)		Series	Total product to receiver (mg/image h)	Image (%)	Retention (%)	Pocket recovery (mg/tank h)	Collection rate (mg/tank h)	
	Natural	Enriched						Collector I	Collector II
Titanium-49	5.51	68-81				63.2	2.36	2.36	
Titanium-50	5.34	67-83				62.8	2.27	2.27	
Tungsten-180	0.135	>8	MT	218.8	70.6	733.0	1.53	1.53	1.53
Tungsten-182	26.40	>94				85.0	34.7	0	34.7
Tungsten-183	14.40	>81				104.0	23.1	23.1	0
Tungsten-184	30.6	>94				84.8	40.1	0	40.1
Tungsten-186	28.4	>97				84.4	37.0	37.0	37.0
Vanadium-50	0.24	36	IT	43.2	71.8	54.8	0.44	0.44	
Ytterbium-168	0.14	13-24	QV	88.4	69.3	303.0	0.260	0.260	0.260
Ytterbium-170	3.03	>78				102.0	1.90	1.90	0
Ytterbium-171	14.31	>95				100.0	8.80	0	8.80
Ytterbium-172	21.82	>97				90.0	12.0	12.0	0
Ytterbium-173	16.13	>92				95.0	9.40	0	9.40
Ytterbium-174	31.84	>98				94.0	18.3	18.3	0
Ytterbium-176	12.73	>96				85.0	6.63	6.63	6.63
Zinc-64	48.89	>98.8	QU	134.8	75.6	51.8	25.8	25.8	
Zinc-66	27.82	>98				75.2	21.3	21.3	
Zinc-67	4.14	89-93				58.7	2.48	2.48	

Table 2 (continued)

Isotope	Isotopic composition (at. %) Natural	Enriched	Series	Total product to receiver (mg/innage h)	Innage (%)	Retention (%)	Pocket recovery (mg/tank h)	Collection rate (mg/tank h) Collector I	Collector II
Zinc-68	18.54	97–99				83.5	15.8	15.8	
Zinc-70	0.617	65–86				78.8	0.495	0.495	
Zirconium-90	51.46	97–99	PN	33.9	76.3	95.2	12.7	12.7	0
Zirconium-91	11.23	88–94				81.5	2.37	0	2.37
Zirconium-92	17.11	>98				85.0	3.76	3.76	0
Zirconium-94	17.40	>98				82.2	3.70	3.70	3.70
Zirconium-96	2.80	>95				47.3	0.343	0.343	0.343

[a]Total product to receiver = (average total ion current)(0.0373) (atomic weight of element); pocket recovery = (total product to receiver)(at. % natural abundance/100)(% innage/100)(% retention/100); % retention = (100 x recovered weight)/(estimated weight).

[b]Separations in both 180° and 255° machine.

[c]Separation in 255° machine.

[d]Two-arc equipment.

Table 3. Generally achieved isotopic separation rates, in order of increasing productivity

Isotope	Separation rates (tank h/mg)	Separation rates (mg/tank h)	Separation rates (μmol/tank h)
Calcium-46	181.8	0.0055	0.120
Potassium-40	125.0	0.008	0.200
Sulfur-36	100.0	0.010	0.280
Osmium-184	43.5	0.023	0.125
Dysprosium-156	29.4	0.034	0.218
Vanadium-50	22.7	0.044	0.880
Platinum-190	20.4	0.049	0.259
Dysprosium-158	18.9	0.053	0.335
Hafnium-174	17.5	0.057	0.328
Mercury-196	14.7	0.068	0.347
Tellurium-120	12.4	0.081	0.675
Barium-130	11.8	0.085	0.654
Cerium-136	10.1	0.099	0.728
Calcium-43	9.09	0.110	2.56
Selenium-74	8.33	0.120	1.62
Barium-132	7.30	0.137	1.04
Calcium-48	6.41	0.156	3.25
Gadolinium-152	6.02	0.166	1.09
Europium-162	5.75	0.174	1.07
Sulfur-33	5.75	0.174	5.27
Ruthenium-98	4.98	0.201	2.05
Osmium-186	4.93	0.203	1.09
Platinum-192	4.35	0.230	1.20
Iron-58	4.26	0.235	4.05
Tin-115	4.18	0.239	2.08
Ytterbium-168	3.85	0.260	1.55
Cerium-138	3.80	0.263	1.91
Tin-114	2.92	0.343	3.01
Zirconium-96	2.92	0.343	3.57
Lanthanum-138	2.83	0.353	2.56
Mercury-198	2.40	0.416	2.10
Calcium-42	2.28	0.438	10.4
Osmium-187	2.19	0.457	2.44
Mercury-204	2.11	0.475	2.33
Palladium-102	2.08	0.481	4.72
Zinc-70	2.02	0.495	7.07
Tin-112	1.92	0.520	4.64
Strontium-84	1.87	0.534	6.36
Ruthenium-96	1.52	0.659	6.86
Tellurium-123	1.45	0.692	5.63
Hafnium-176	1.35	0.742	4.22
Potassium-41	1.22	0.820	20.0
Silicon-30	1.09	0.920	30.7

Table 3 (continued)

Isotope	Separation rates (tank h/mg)	(mg/tank h)	(μmol/tank h)
Chromium-54	1.080	0.925	17.10
Erbium-164	1.060	0.941	5.74
Cadmium-108	0.990	1.01	9.35
Mercury-201	0.980	1.02	5.07
Cadmium-106	0.901	1.11	5.52
Mercury-199	0.862	1.16	5.83
Lutetium-176	0.862	1.16	6.59
Nickel-64	0.775	1.29	20.20
Silicon-29	0.758	1.32	45.50
Gadolinium-154	0.709	1.41	9.16
Ruthenium-100	0.667	1.50	15.0
Sulfur-34	0.658	1.52	44.7
Tellurium-122	0.658	1.52	12.5
Tungsten-180	0.654	1.53	8.50
Dysprosium-160	0.610	1.64	10.3
Ruthenium-99	0.610	1.64	16.6
Calcium-44	0.599	1.67	38.0
Iron-57	0.588	1.70	29.8
Nickel-64	0.585	1.71	28.0
Mercury-200	0.575	1.74	8.70
Selenium-82	0.546	1.83	22.3
Ruthenium-101	0.535	1.87	18.5
Germanium-76	0.526	1.90	24.7
Ytterbium-170	0.526	1.90	11.2
Selenium-77	0.505	1.98	25.7
Barium-134	0.485	2.06	15.4
Mercury-202	0.485	2.06	10.2
Lead-204	0.474	2.11	10.3
Platinum-198	0.469	2.13	10.8
Chromium-50	0.448	2.23	44.6
Selenium-76	0.441	2.27	29.9
Titanium-50	0.441	2.27	45.4
Indium-113	0.437	2.29	20.3
Osmium-188	0.426	2.35	12.5
Titanium-49	10424	2.36	48.2
Ruthenium-104	0.422	2.37	22.8
Zirconium-91	0.422	2.37	26.0
Tantalum-180	0.410	2.44	13.6
Zinc-67	0.403	2.48	37.0
Germanium-73	0.395	2.53	34.7
Neodymium-150	0.391	2.56	17.1
Samarium-144	0.362	2.76	19.2
Chlorine-37	0.350	2.86	77.3

Table 3 (continued)

Isotope	Separation rates (tank h/mg)	(mg/tank h)	(μmol/tank h)
Osmium-189	0.350	2.86	15.1
Tin-122	0.347	2.88	23.6
Neodymium-148	0.345	2.90	19.6
Cerium-142	0.336	2.98	21.0
Ruthenium-102	0.314	3.18	31.2
Tin-124	0.281	3.56	28.7
Hafnium-179	0.278	3.60	20.1
Iron-54	0.272	3.67	68.0
Zirconium-94	0.270	3.70	39.4
Zirconium-92	0.266	3.76	40.9
Titanium-47	0.262	3.81	81.1
Hafnium-177	0.261	3.83	21.6
Titanium-46	0.257	3.89	84.6
Tellurium-124	0.244	4.10	33.1
Barium-135	0.243	4.11	30.4
Neodymium-145	0.224	4.47	30.8
Magnesium-25	0.223	4.49	179.6
Gadolinium-155	0.212	4.71	30.4
Magnesium-26	0.205	4.87	187.3
Chromium-53	0.196	5.10	96.2
Palladium-110	0.190	5.27	47.9
Palladium-104	0.189	5.28	50.8
Nickel-62	0.188	5.32	85.8
Osmium-190	0.182	5.49	28.9
Tin-117	0.181	5.51	47.1
Tin-119	0.179	5.58	46.9
Cadmium-116	0.179	5.59	48.2
Selenium-78	0.170	5.87	75.3
Samarium-150	0.163	6.15	41.0
Neodymium-143	0.159	6.30	44.1
Germanium-70	0.155	6.45	92.1
Ytterbium-176	0.151	6.63	37.7
Gadolinium-156	0.148	6.76	43.3
Gadolinium-157	0.146	6.87	43.8
Hafnium-178	0.142	7.05	39.6
Osmium-192	0.139	7.18	37.4
Tellurium-125	0.139	7.18	57.4
Hafnium-123	0.136	7.36	59.8
Strontium-87	0.135	7.43	85.4
Barium-136	0.123	8.11	59.6
Gadolinium-158	0.122	8.22	52.0
Platinum-196	0.122	8.22	41.9
Neodymium-146	0.120	8.30	56.9
Erbium-170	0.119	8.38	49.3

Table 3 (continued)

Isotope	Separation rates		
	(tank h/mg)	(mg/tank h)	(μmol/tank h)
Gadolinium-160	0.119	8.39	52.4
Molybdenum-100	0.117	8.52	85.2
Iridium-191	0.115	8.72	45.7
Ytterbium-171	0.114	8.80	51.5
Bromine-81	0.107	9.31	114.9
Cadmium-113	0.107	9.34	82.7
Tin-116	0.107	9.34	80.5
Ytterbium-173	0.106	9.40	54.3
Cadmium-111	0.106	9.41	85.6
Molybdenum-97	0.106	9.41	97.0
Palladium-105	0.101	9.95	94.8
Cadmium-110	0.100	10.0	90.9
Molybdenum-94	0.100	10.0	106.4
Samarium-148	0.099	10.1	68.2
Barium-137	0.098	10.2	74.5
Vanadium-51	0.0971	10.3	202.0
Germanium-72	0.0962	10.4	144.4
Strontium-86	0.0952	10.5	122.1
Bromine-79	0.0943	10.6	134.2
Chlorine-35	0.0943	10.6	302.9
Platinum-195	0.0935	10.7	54.9
Dysprosium-161	0.0893	11.2	69.6
Samarium-149	0.0877	11.4	76.5
Platinum-194	0.0870	11.5	59.3
Neodymium-144	0.0847	11.8	81.9
Palladium-106	0.0833	12.0	113.2
Ytterbium-172	0.0833	12.0	69.8
Dysprosium-163	0.0794	12.6	77.3
Zirconium-90	0.0787	12.7	141.1
Ruthenium-87	0.0781	12.8	147.1
Samarium-147	0.0781	12.8	87.1
Palladium-108	0.0775	12.9	119.4
Tellurium-126	0.0769	13.0	103.2
Neodymium-142	0.0758	13.2	93.0
Selenium-80	0.0758	13.2	165.0
Gallium-71	0.0752	13.3	187.3
Erbium-167	0.0746	13.4	80.2
Germanium-74	0.0735	13.6	183.8
Dysprosium-164	0.0714	14.0	85.4
Dysprosium-162	0.0680	14.7	90.7
Potassium-39	0.0676	14.8	379.5
Erbium-168	0.0667	15.0	89.3
Tin-118	0.0667	15.0	127.1

Table 3 (continued)

Isotope	Separation rates		
	(tank h/mg)	(mg/tank h)	(μmol/tank h)
Molybdenum-92	0.0654	15.3	166.3
Molybdenum-95	0.0645	15.5	163.2
Zinc-68	0.0633	15.8	232.4
Rhenium-185	0.0585	17.1	92.4
Iridium-193	0.0575	17.4	90.2
Molybdenum-96	0.0556	18.0	187.5
Ytterbium-174	0.0546	18.3	105.2
Europium-153	0.0541	18.5	120.9
Cadmium-112	0.0535	18.7	167.0
Europium-151	0.0535	18.7	123.8
Samarium-154	0.0532	18.8	122.1
Erbium-166	0.0526	19.0	114.5
Cadmium-114	0.0481	20.8	182.5
Silver-109	0.0472	21.2	194.5
Zinc-66	0.0469	21.3	322.7
Molybdenum-98	0.0441	22.7	231.6
Silver-107	0.0439	22.8	213.1
Tungsten-183	0.0433	23.1	126.2
Tin-120	0.0420	23.8	198.3
Samarium-152	0.0415	24.1	158.6
Gallium-69	0.0413	24.2	350.7
Tellurium-130	0.0391	25.6	196.9
Zinc-64	0.0389	25.7	40.1
Copper-65	0.0388	25.8	396.9
Lead-206	0.0380	26.3	127.7
Tellurium-128	0.0380	26.3	205.5
Lead-207	0.0379	26.4	127.5
Cerium-140	0.0376	26.6	190.0
Antimony-121	0.0357	28.0	231.4
Antimony-123	0.0340	29.4	239.0
Lanthanum-139	0.0377	29.7	213.7
Ruthenium-85	0.0327	30.6	360.0
Magnesium-24	0.0318	31.4	1308.3
Rhenium-187	0.0313	32.0	171.1
Tungsten-182	0.0288	34.7	190.7
Silicon-28	0.0285	35.1	1253.6
Tungsten-186	0.0270	37.0	198.9
Titanium-48	0.0267	37.4	779.2
Tungsten-184	0.0249	40.1	217.9
Nickel-60	0.0244	41.0	683.3
Lutetium-175	0.0226	44.2	252.6
Barium-138	0.0222	45.1	326.8
Tantalum-181	0.0221	45.2	249.7

Table 3 (continued)

Isotope	Separation rates		
	(tank h/mg)	(mg/tank h)	(μmol/tank h)
Chromium-52	0.0216	46.4	892.3
Thallium-203	0.0211	47.3	233.0
Sulfur-32	0.0209	47.8	1493.8
Calcium-40	0.0182	54.9	1372.5
Indium-115	0.0180	55.6	483.5
Copper-63	0.0169	59.1	938.1
Lead-208	0.0163	61.2	294.2
Iron-56	0.0144	69.4	1239.3
Strontium-88	0.0127	78.9	896.6
Nickel-58	0.0103	97.5	1681.0
Thallium-205	0.0091	110.0	536.6

Table 4. Average annual quantities of stable isotopes sold in five-year intervals

Isotope	1970–1974 (mg)	1975–1979 (mg)	1980–1984 (mg)
Antimony-121	828	513	534
Antimony-123	686	557	919
Barium-130	231	80	53
Barium-132	267	283	47
Barium-134	307	1,567	43
Barium-135	498	740	1,041
Barium-136	549	3,575	1,075
Barium-137	439	1,734	551
Barium-138	5,210	10,885	2,878
Bromine-79	757	1,530	1,702
Bromine-81	1,111	887	919
Cadmium-106	325	400	189
Cadmium-108	1,038	94	83
Cadmium-110	3,222	2,118	2,158
Cadmium-111	2,024	1,221	2,056
Cadmium-112	45,959	30,436	43,145
Cadmium-113	2,195	21,996	2,053
Cadmium-114	81,911	38,649	4,620
Cadmium-116	2,533	1,527	1,447
Calcium-40	6,677	35,226	4,090
Calcium-42	1,019	1,236	991
Calcium-43	918	713	38
Calcium-44	4,261	5,069	2,683
Calcium-46	83	72	37
Calcium-48	1,552	1,509	979
Cerium-136	265	82	3
Cerium-138	98	7	0
Cerium-140	8,986	7,309	18,534
Cerium-142	1,353	1,077	544

Table 4 (continued)

Isotope	1970-1974 (mg)	1975-1979 (mg)	1980-1984 (mg)
Chlorine-35	7,903	12,397	3,189
Chlorine-37	3,965	7,069	642
Chromium-50	3,753	5,275	2,453
Chromium-52	3,265	2,743	1,073
Chromium-53	1,747	1,227	862
Chromium-54	622	1,045	1,225
Copper-63	14,381	12,480	32,924
Copper-65	7,187	7,095	14,313
Dysprosium-156	19	115	27
Dysprosium-158	83	203	62
Dysprosium-160	435	723	707
Dysprosium-161	1,606	1,582	2,507
Dysprosium-162	3,023	797	4,998
Dysprosium-163	695	2,532	2,220
Dysprosium-164	3,359	2,483	7,310
Erbium-162	27	48	31
Erbium-164	416	357	97
Erbium-166	2,026	2,322	2,355
Erbium-167	2,103	1,682	3,070
Erbium-168	4,507	6,103	3,396
Erbium-170	2,589	3,072	2,901
Europium-151	2,836	4,993	1,909
Europium-153	3,557	4,444	2,987
Gadolinium-152	103	282	233
Gadolinium-154	411	375	271
Gadolinium-155	2,171	1,064	314

Table 4 (continued)

Isotope	1970-1974 (mg)	1975-1979 (mg)	1980-1984 (mg)
Gadolinium-156	1,100	1,698	1,985
Gadolinium-157	1,529	834	416
Gadolinium-158	2,259	1,206	1,342
Gadolinium-160	7,341	12,929	13,087
Gallium-69	641	971	1,736
Gallium-71	402	546	1,796
Germanium-70	2,929	4,407	2,401
Germanium-72	2,484	3,053	1,297
Germanium-73	1,137	420	241
Germanium-74	6,334	5,220	6,225
Germanium-76	1,066	892	588
Hafnium-174	26	22	3
Hafnium-176	2,007	252	84
Hafnium-177	564	217	464
Hafnium-178	1,614	618	333
Hafnium-179	2,077	377	583
Hafnium-180	3,883	1,370	776
Indium-113	220	466	70
Indium-115	763	472	278
Iridium-191	51	341	838
Iridium-193	35	257	1,000
Iron-54	5,981	8,079	6,610
Iron-56	13,589	1,345,398	30,998
Iron-57	14,079	8,692	6,507
Iron-58	933	799	1,624

Table 4 (continued)

Isotope	1970-1974 (mg)	1975-1979 (mg)	1980-1984 (mg)
Lanthanum-138	73	117	60
Lanthanum-139	100	51	20
Lead-204	1,668	1,385	143
Lead-206	5,522	7,683	3,708
Lead-207	9,390	8,818	7,194
Lead-208	22,467	89,467	47,954
Lutetium-175	547	1,542	344
Lutetium-176	103	212	1,192
Magnesium-24	7,301	8,867	5,329
Magnesium-25	1,753	3,667	2,917
Magnesium-26	4,153	9,123	1,762
Mercury-196	626	375	21
Mercury-198	304	221	151
Mercury-199	303	296	205
Mercury-200	426	370	157
Mercury-201	148	170	396
Mercury-202	1,075	292	173
Mercury-204	664	980	395
Molybdenum-92	7,437	7,967	2,597
Molybdenum-94	1,759	1,141	1,570
Molybdenum-95	2,585	3,981	16,170
Molybdenum-96	2,621	4,851	4,745
Molybdenum-97	690	1,563	2,547
Molybdenum-98	226,965	34,301	1,594
Molybdenum-100	3,925	7,002	5,234
Neodymium-142	7,604	3,078	1,357
Neodymium-143	1,120	1,091	996

Table 4 (continued)

Isotope	1970-1974 (mg)	1975-1979 (mg)	1980-1984 (mg)
Neodymium-144	2,378	5,623	2,407
Neodymium-145	683	1,550	1,653
Neodymium-146	4,917	4,078	2,074
Neodymium-148	1,710	1,740	1,115
Neodymium-150	3,689	4,393	2,036
Nickel-58	81,694	86,488	52,113
Nickel-60	27,905	22,454	52,129
Nickel-61	1,135	1,302	443
Nickel-62	13,373	20,737	8,449
Nickel-64	4,304	1,695	1,422
Osmium-184	13	2	1
Osmium-186	40	72	24
Osmium-187	73	42	31
Osmium-188	103	250	388
Osmium-189	94	279	398
Osmium-190	71	1,566	1,471
Osmium-192	0	1,488	987
Palladium-102	61	134	143
Palladium-104	327	694	421
Palladium-105	866	480	757
Palladium-106	562	1,014	510
Palladium-108	1,297	2,131	1,553
Palladium-110	738	1,548	492
Platinum-190	17	1	14
Platinum-192	84	66	72
Platinum-194	988	3,177	366
Platinum-195	334	1,116	670
Platinum-196	377	2,023	444
Platinum-198	164	1,903	542

Table 4 (continued)

Isotope	1970-1974 (mg)	1975-1979 (mg)	1980-1984 (mg)
Potassium-39	1,114	995	1,405
Potassium-40	270	39	47
Potassium-41	2,308	1,264	519
Rhenium-185	1,214	1,018	1,709
Rhenium-187	890	953	802
Rubidium-85	3,447	2,547	2,353
Rubidium-87	6,538	3,802	5,230
Ruthenium-96	246	302	410
Ruthenium-98	18	42	20
Ruthenium-99	567	511	312
Ruthenium-100	166	474	312
Ruthenium-101	240	358	1,246
Ruthenium-102	942	3,554	835
Ruthenium-104	461	659	875
Samarium-144	3,222	4,146	1,098
Samarium-147	2,986	1,445	2,469
Samarium-148	2,742	2,297	1,432
Samarium-149	5,570	2,291	1,912
Samarium-150	2,919	2,300	1,947
Samarium-152	8,306	9,104	11,677
Samarium-154	12,884	15,477	19,899
Selenium-74	1,135	514	205
Selenium-76	829	705	1,247
Selenium-77	216	1,419	420
Selenium-78	940	1,172	423
Selenium-80	3,290	1,619	1,995
Selenium-82	847	575	605

Table 4 (continued)

Isotope	1970-1974 (mg)	1975-1979 (mg)	1980-1984 (mg)
Silicon-28	2,570	3,293	1,867
Silicon-29	970	1,833	3,672
Silicon-30	1,965	3,153	1,885
Silver-107	2,246	5,142	8,819
Silver-109	1,725	3,550	7,467
Strontium-84	1,979	776	508
Strontium-86	3,057	4,459	2,551
Strontium-87	1,818	5,198	1,662
Strontium-88	25,639	18,446	20,893
Sulfur-32	982	1,055	1,055
Sulfur-33	319	427	342
Sulfur-34	1,584	1,554	1,004
Sulfur-36	9	5	15
Tantalum-180	6	0	8
Tantalum-181	0	0	0
Tellurium-120	75	20	16
Tellurium-122	7,519	7,885	497
Tellurium-123	475	87	264
Tellurium-124	7,151	21,360	35,470
Tellurium-125	2,783	908	1,690
Tellurium-126	2,395	2,036	3,033
Tellurium-128	9,572	5,691	8,109
Tellurium-130	5,848	6,244	9,133
Thallium-203	7,568	255,467	723,558
Thallium-205	5,536	11,080	2,979
Tin-112	6,071	3,370	1,948
Tin-114	171	347	221

Table 4 (continued)

Isotope	1970-1974 (mg)	1975-1979 (mg)	1980-1984 (mg)
Tin-115	44	15	8
Tin-116	4,060	3,668	2,450
Tin-117	2,827	13,061	12,513
Tin-118	10,728	6,147	4,265
Tin-119	9,347	10,012	6,904
Tin-120	12,822	4,443	4,244
Tin-122	2,350	2,604	2,345
Tin-124	3,803	8,126	14,184
Titanium-46	1,928	1,530	2,113
Titanium-47	910	1,037	2,041
Titanium-48	3,846	4,020	2,710
Titanium-49	573	1,886	2,167
Titanium-50	1,363	6,942	729
Tungsten-180	239	107	28
Tungsten-182	38,517	2,284	1,096
Tungsten-183	902	1,264	992
Tungsten-184	36,785	2,279	931
Tungsten-186	40,180	1,914	2,130
Vanadium-50	7	16	7
Vanadium-51	84	10	0
Ytterbium-168	1,077	1,544	747
Ytterbium-170	1,540	1,101	225
Ytterbium-171	1,066	1,846	1,549
Ytterbium-172	1,290	1,251	649
Ytterbium-173	1,306	1,322	879
Ytterbium-174	4,144	2,886	1,465
Ytterbium-176	2,778	2,644	2,947

Table 4 (continued)

Isotope	1970-1974 (mg)	1975-1979 (mg)	1980-1984 (mg)
Zinc-64	4,498	8,555	3,541
Zinc-66	3,428	1,762	3,956
Zinc-67	2,183	1,441	3,341
Zinc-68	27,612	60,482	143,358
Zinc-70	240	278	602
Zirconium-90	6,340	6,304	4,947
Zirconium-91	1,618	972	301
Zirconium-92	1,110	1,242	731
Zirconium-94	1,426	475	873
Zirconium-96	304	248	62

Table 5. Distribution of stable isotope sales and revenue, 1970-1984

FY	Domestic		Foreign		Project		Total	
	(mg)	($)	(mg)	($)	(mg)	($)	(mg)	($)
1970	284,300	377,696	403,951	556,926	183,752	144,504	872,003	1,079,126
1971	248,378	262,212	399,250	558,801	150,495	101,802	798,123	922,815
1972	880,445	346,127	423,065	610,932	263,365	147,504	1,566,875	1,104,563
1973	626,676	578,988	526,342	761,089	255,607	183,784	1,408,625	1,523,861
1974	418,353	457,028	640,122	924,340	184,808	240,539	1,243,283	1,621,907
1975	270,553	386,855	523,476	882,401	109,911	148,970	903,940	1,418,226
1976[a]	531,850	506,534	555,614	903,420	227,362	157,819	1,314,826	1,567,773
1977	463,986	454,904	646,803	741,716	156,277	123,008	1,267,066	1,319,628
1978	405,587	421,433	569,889	852,132	280,800	133,318	1,256,276	1,406,883
1979	769,807	975,961	675,600	1,019,572	116,908	426,377	1,562,315	2,421,910
1980	766,034	1,413,345	689,579	1,043,662	267,149	179,445	1,722,762	2,636,402
1981	1,495,077	2,648,099	395,639	940,965	129,846	154,864	2,020,562	3,743,928
1982	1,096,394	2,325,956	398,055	1,200,814	231,256	190,335	1,725,705	3,717,105
1983	916,570	1,795,435	260,793	1,063,113	208,095	188,720	1,385,458	3,047,268
1984	325,180	659,086	536,741	1,438,279	283,255	536,721	1,145,176	2,634,086
Total	9,499,190	13,609,659	7,644,919	13,498,162	3,048,886	3,057,710	20,192,995	30,165,531

[a]One-time sale of ^{56}Fe is not included.

Table 6. Zero-inventory isotopes and potential loss in annual sales revenue, 12/31/84

Isotope	Avg. sales 1980–1984 (mg/year)	Sales replacement time (tank h)	Annual sales value[a] ($)
Antimony-121	534	19	830
Barium-134	43	21	115
Bromine-79	1,702	161	1,275
Bromine-81	919	99	775
Cadmium-108	83	82	65
Cadmium-113	2,053	220	5,645
Dysprosium-156	27	794	490
Erbium-162	31	178	205
Europium-151	1,909	102	870
Indium-113	70	31	920
Lutetium-176	1,192	1,028	4,055
Magnesium-25	2,917	650	5,835
Palladium-102	143	286	6,070
Potassium-40	47	5,875	3,275
Potassium-41	519	633	3,325
Rhenium-185	1,709	100	3,250
Samarium-147	2,469	193	2,590
Tantalum-181	0	0	0
Titanium-46	2,113	544	3,120
Titanium-49	2,167	919	2,235
Titanium-50	729	322	890
Tungsten-183	992	43	385
Vanadium-51	0	0	0
Total[b] (23 isotopes)			46,220

[a]Based on last catalog listing.
[b]Forty additional isotopes have <6-month inventory balance.

Table 7. Annual revenue from "best selling" isotopes, 1970-1984

Year	Isotope and revenue ($)						
	Ca-40	Ca-43	Ca-44	Ca-46	Ca-48	Cd-112	Cd-114
1970	3,056	11,520	14,375	66,300	16,206	1,061	22,475
1971	1,506	2,292	8,634	48,605	11,314	15,062	3,908
1972	2,103	11,662	5,479	15,715	14,010	7,171	16,661
1973	1,402	4,694	10,622	61,370	20,147	13,709	21,346
1974	2,534	46,449	7,119	47,551	132,249	27,691	20,295
1975	3,189	51,188	8,237	60,949	42,884	29,536	4,873
1976	13,232	3,400	18,160	54,180	34,335	27,940	30,144
1977	9,375	9,984	5,111	41,539	43,147	2,490	33,400
1978	2,882	1,428	12,097	103,663	59,020	915	4,247
1979	20,627	14,991	7,668	50,337	353,966	7,216	3,650
1980	1,067	10,598	9,059	14,542	73,464	16,343	1,914
1981	1,253	4,000	9,268	84,916	67,425	5,900	1,890
1982	1,809	17,857	25,245	33,631	275,500	4,221	1,515
1983	1,725	2,911	12,288	13,088	250,992	39,200	3,180
1984	2,504	6,045	9,415	238,367	212,318	40,450	1,716
Total	68,264	199,019	162,777	934,753	1,606,977	238,905	171,214
Average	4,550	13,268	10,852	62,317	107,132	15,927	11,414

Table 7 (continued)

Year	Isotope and revenue ($)						
	Cl-37	Cr-54	Gd-160	Fe-54	Fe-57	Fe-58	Pb-208
1970	2,755	2,379	3,469	6,813	47,281	26,013	2,412
1971	4,438	2,587	5,437	8,629	41,591	15,667	3,132
1972	2,896	1,397	2,626	10,240	43,099	24,617	4,734
1973	8,126	3,112	1,752	12,119	37,851	17,684	4,375
1974	9,871	3,726	2,973	4,927	34,992	15,919	8,490
1975	15,924	11,219	1,557	16,744	41,796	27,119	5,491
1976	21,608	3,158	8,477	14,501	50,109	14,705	11,132
1977	3,912	1,373	4,507	8,087	14,444	17,547	19,940
1978	29,027	15,998	1,950	11,434	32,218	20,894	18,057
1979	8,339	1,491	27,954	8,661	24,029	16,723	24,651
1980	3,256	5,109	3,169	21,000	49,649	32,607	34,129
1981	1,724	66,571	22,180	11,179	58,334	7,943	8,659
1982	1,258	7,008	3,740	10,149	77,241	165,648	7,804
1983	1,850	0	5,083	8,158	46,106	60,337	10,744
1984	14,192	1,572	6,715	9,813	36,307	1,159	6,558
Total	129,176	126,700	101,589	162,454	638,047	464,552	170,308
Average	8,612	8,447	6,773	10,830	42,536	3,970	11,354

Table 7 (continued)

Year	Isotope and revenue ($)						
	Mg-26	Hg-196	Hg-204	Mo-98	Ni-58	Ni-60	Ni-62
1970	1,598	212,937	2,415	121,429	8,429	1,126	8,964
1971	2,187	166,757	4,579	137,74	2,516	1,555	10,248
1972	6,253	170,983	2,150	175,058	13,767	643	12,518
1973	4,317	181,020	6,312	356,731	1,969	16,264	10,285
1974	7,322	229,053	7,400	202,071	24,845	876	48,016
1975	6,185	179,079	6,360	37,202	5,464	2,327	10,765
1976	6,967	217,063	7,740	41,652	8,183	5,783	56,761
1977	16,494	70,483	3,925	48,500	11,392	1,950	40,428
1978	27,486	121,009	9,830	28,802	19,045	1,839	25,229
1979	11,729	126,683	20,146	26,350	7,949	7,431	44,869
1980	4,622	27,792	24,403	2,267	7,455	19,374	19,989
1981	8,776	1,109	0	1,593	8,599	9,386	30,858
1982	0	14,715	1,500	2,500	3,977	22,084	68,174
1983	555	15,957	0	700	6,887	875	79,830
1984	750	10,231	7,819	2,604	46,839	2,520	78,045
Total	105,241	1,744,871	104,579	1,185,193	177,816	94,033	544,979
Average	7,016	116,325	6,972	79,013	11,821	6,269	36,332

Table 7 (continued)

Year	Isotope and revenue ($)						
	Ni-64	Pd-102	Rb-87	Ru-102	Sm-144	Se-74	Sr-84
1970	3,323	588	5,188	666	4,048	5,950	63,620
1971	3,901	935	9,242	437	3,475	8,981	24,129
1972	10,103	5,676	9,463	4,562	2,805	11,252	39,582
1973	67,294	5,500	7,899	1,140	2,129	21,790	54,666
1974	12,785	3,630	11,152	403	1,194	86,485	34,485
1975	12,655	2,491	18,496	31	1,369	63,735	51,064
1976	7,387	9,130	9,592	1,939	1,964	54,208	36,367
1977	12,311	1,925	5,515	890	4,265	64,630	13,361
1978	35,004	7,252	7,167	22,436	4,945	7,954	26,528
1979	6,391	2,203	24,239	240	2,526	31,060	2,961
1980	9,856	0	29,089	320	1,720	26,851	78,964
1981	28,496	748	14,368	0	815	16,785	20,664
1982	30,681	0	15,760	0	134	25,667	12,571
1983	6,970	1,185	10,163	0	177	48,516	9,332
1984	14,162	27,040	24,169	1,443	22,313	8,944	9,659
Total	261,319	68,303	201,502	34,507	53,879	482,808	477,953
Average	17,421	4,554	13,433	2,300	3,592	32,187	31,864

Table 7 (continued)

Year	Isotope and revenue ($)						
	Te-122	Te-123	Te-124	Tl-203	Sn-112	Ti-50	Yb-168
1970	2,849	10,498	589	1,879	34,488	3,490	5,334
1971	10,745	67	2,876	846	34,950	1,483	5,599
1972	27,527	1,882	3,030	716	44,563	5,035	5,692
1973	11,425	4,599	10,541	5,401	68,839	3,002	6,719
1974	72,461	775	34,263	2,163	84,082	1,851	14,001
1975	67,405	332	8,421	44,015	109,754	4,523	44,808
1976	109,455	2,370	55,945	103,061	33,776	2,316	3,281
1977	69,351	150	64,172	138,935	94,888	10,760	16,358
1978	7,683	1,190	73,245	102,724	8,902	4,243	26,979
1979	12,756	1,000	348,762	487,882	10,682	33,602	28,270
1980	10,236	7,150	156,706	1,203,257	56,873	1,426	21,550
1981	4,874	2,431	385,598	2,114,864	54,328	1,251	41,327
1982	22,653	1,772	628,828	1,443,312	8,323	1,131	64,155
1983	998	1,846	476,230	1,207,183	44,541	154	185,647
1984	5,334	25,555	113,382	369,324	20,898	0	219,362
Total	435,752	61,617	2,362,588	7,225,562	709,887	74,267	689,082
Average	29,050	4,108	157,506	481,704	47,326	4,951	45,939

Table 7 (continued)

Year	Isotope and revenue ($)		
	Zn-68	Zn-70	Total
1970	3,228	3,323	732,074
1971	5,004	7,040	618,088
1972	26,772	2,530	744,972
1973	39,561	3,933	1,109,645
1974	32,946	1,786	1,278,831
1975	72,649	9,072	1,078,908
1976	31,621	5,242	1,116,884
1977	11,096	4,469	924,104
1978	115,277	4,151	1,002,750
1979	74,316	19,929	1,902,279
1980	162,675	35,848	2,184,329
1981	257,711	23,088	3,378,911
1982	313,472	14,395	3,328,430
1983	206,025	8,029	2,767,462
1984	635,548	16,194	2,249,236
Total	1,987,901	159,029	24,416,903
Average	132,527	10,602	1,627,794

Table 8. Comparison of sales with production capability, 1970-1984

Isotope	Total sales (mg)	Production requirement (tank h)	Sales/production capability (%)	Production effort (%)
Antimony-121	9,377	335	91	
Antimony-123	10,815	368	100	0.02
Barium-130	1,818	21,388	98	
Barium-132	2,984	21,781	100	1.46
Barium-132	9,587	4,654	63	
Barium-135	11,394	2,772	19	
Barium-136	25,998	3,206	43	
Barium-137	13,618	1,335	9	
Barium-138	94,863	2,103	28	
Bromine-79	19,945	1,882	100	0.13
Bromine-81	14,585	1,567	83	
Cadmium-106	4,574	4,121	9	
Cadmium-108	6,076	6,016	13	
Cadmium-110	37,488	3,749	12	
Cadmium-111	26,502	2,816	20	
Cadmium-112	597,702	31,963	100	2.14
Cadmium-113	131,220	14,049	100	0.94
Cadmium-114	625,900	30,091	94	
Cadmium-116	27,533	4,925	11	
Calcium-40	229,964	4,189	2	
Calcium-42	16,231	37,057	21	
Calcium-43	8,349	75,900	43	
Calcium-44	60,063	35,966	21	
Calcium-46	961	174,727	100	11.71
Calcium-48	20,198	129,474	74	
Cerium-136	1,747	17,646	100	1.18
Cerium-138	526	2,000	11	
Cerium-140	174,149	4,99	28	

Table 8 (continued)

Isotope	Total sales (mg)	Production requirement (tank h)	Sales/production capability (%)	Production effort (%)
Chlorine-35	117,446	11,080	54	
Chlorine-37	58,373	20,140	100	1.35
Chromium-50	57,404	25,742	100	1.73
Chromium-52	35,409	763	3	
Chromium-53	19,181	3,761	15	
Chromium-54	14,460	15,632	61	
Copper-63	265,963	4,500	81	
Copper-65	142,973	5,542	100	0.37
Dysprosium-156	806	23,706	75	
Dysprosium-158	1,682	31,736	100	2.13
Dysprosium-160	9,324	5,685	26	
Dysprosium-161	28,475	2,542	27	
Dysprosium-162	44,087	2,999	14	
Dysprosium-163	27,235	2,162	23	
Dysprosium-164	6,5761	4,697	21	
Erbium-162	532	3,057	42	
Erbium-164	4,350	4,626	64	
Erbium-166	33,512	1,764	38	
Erbium-167	34,271	2,558	100	0.17
Erbium-168	70,030	4,669	100	0.31
Erbium-170	42,808	5,108	71	
Europium-151	48,686	2,604	88	
Europium-153	54,940	2,970	100	0.20
Gadolinium-142	3,086	15,590	94	
Gadolinium-154	5,284	3,748	23	
Gadolinium-155	17,746	3,768	99	
Gadolinium-156	23,918	3,538	21	

Table 8 (continued)

Isotope	Total sales (mg)	Production requirement (tank h)	Sales/production capability (%)	Production effort (%)
Gadolinium-157	13,895	2,023	60	
Gadolinium-158	24,033	2,924	18	
Gadolinium-160	166,786	19,879	100	1.33
Gallium-69	16,737	692	67	
Gallium-71	13,717	1,031	100	0.07
Germanium-70	48,688	7,549	100	0.51
Germanium-72	34,172	3,286	44	
Germanium-73	8,991	3,554	47	
Germanium-74	88,893	6,536	87	
Germanium-76	12,732	6,701	89	
Hafnium-174	255	4,474	22	
Hafnium-176	11,718	15,792	100	1.06
Hafnium-177	6,226	1,626	39	
Hafnium-178	12,827	1,961	12	
Hafnium-179	15,186	4,218	100	0.28
Hafnium-180	30,145	4,096	26	
Indium-113	3,777	1,649	100	0.10
Indium-115	7,568	136	8	
Iridium-191	6,147	705	100	0.05
Iridium-193	6,465	372	53	
Iron-54	103,353	28,162	28	
Iron-56	6,949,926	100,143	100	6.70
Iron-57	146,389	86,111	86	
Iron-58	16,776	71,387	71	
Lanthanum-138	1,250	3,541	100	0.24
Lanthanum-139	855	29	1	

Table 8 (continued)

Isotope	Total sales (mg)	Production requirement (tank h)	Sales/production capability (%)	Production effort (%)
Lead-204	15,985	7,576	42	
Lead-206	84,568	3,216	25	
Lead-207	127,014	4,811	100	
Lead-208	799,441	13,063	100	0.32
Lutetium-175	12,162	275	8	
Lutetium-176	3,960	3,414	100	0.23
Magnesium-24	107,485	3,423	22	
Magnesium-25	41,686	9,284	60	
Magnesium-26	75,185	15,438	100	1.03
Mercury-196	5,115	75,221	100	5.04
Mercury-198	3,375	8,113	100	0.54
Mercury-199	4,023	3,468	5	
Mercury-200	4,788	2,752	34	
Mercury-201	3,173	3,111	4	
Mercury-202	7,699	3,737	46	
Mercury-204	10,193	21,459	29	
Molybdenum-92	90,008	5,883	10	
Molybdenum-94	22,352	2,235	4	
Molybdenum-95	113,679	7,334	13	
Molybdenum-96	61,083	3,394	6	
Molybdenum-97	24,002	2,551	4	
Molybdenum-98	1,314,301	57,899	100	3.88
Molybdenum-100	80,805	9,484	16	
Neodymium-142	60,194	4,560	46	
Neodymium-143	16,033	2,545	26	
Neodymium-144	5,044	4,411	45	
Neodymium-145	19,428	4,346	44	

Table 8 (continued)

Isotope	Total sales (mg)	Production requirement (tank h)	Sales/production capability (%)	Production effort (%)
Neodymium-146	55,347	6,668	67	
Neodymium-148	22,822	7,870	40	
Neodymium-150	50,590	19,762	100	1.32
Nickel-58	1,102,478	11,297	28	
Nickel-60	512,441	12,499	31	
Nickel-61	14,399	8,420	21	
Nickel-62	212,796	39,999	100	2.68
Nickel-64	37,105	28,764	72	
Osmium-184	77	3,348	67	
Osmium-186	684	3,369	100	0.23
Osmium-187	731	1,600	100	0.11
Osmium-188	3,707	1,577	47	
Osmium-189	3,857	1,349	84	
Osmium-190	15,539	2,830	84	
Osmium-192	12,177	1,696	34	
Palladium-102	1,689	3,511	100	0.24
Palladium-104	7,210	1,366	78	
Palladium-105	10,514	1,057	60	
Palladium-106	10,431	869	50	
Palladium-108	24,904	1,931	55	
Palladium-110	13,890	2,636	75	
Platinum-190	160	3,265	53	
Platinum-192	1,107	4,813	79	
Platinum-194	22,654	1,970	64	
Platinum-195	10,604	991	32	
Platinum-196	14,215	1,729	56	
Platinum-198	13,045	6,124	100	0.41

Table 8 (continued)

Isotope	Total sales (mg)	Production requirement (tank h)	Sales/production capability (%)	Production effort (%)
Potassium-39	17,574	1,187	3	
Potassium-40	1,686	45,507	100	3.05
Potassium-41	19,937	24,313	53	
Rhenium-185	16,288	953	100	0.06
Rhenium-187	12,424	388	41	
Rubidium-185	41,736	1,364	22	
Rubidium-87	77,853	6,082	100	0.41
Ruthenium-96	3,153	4,757	63	
Ruthenium-98	320	1,592	21	
Ruthenium-99	6,013	3,666	48	
Ruthenium-100	3,828	2,551	34	
Ruthenium-101	5,484	2,933	39	
Ruthenium-102	24,148	7,594	100	0.51
Ruthenium-104	9,100	3,840	51	
Samarium-144	42,334	15,338	100	1.03
Samarium-147	34,500	2,695	36	
Samarium-148	32,350	3,203	42	
Samarium-149	48,870	4,287	56	
Samarium-150	35,832	5,826	76	
Samarium-152	145,435	6,035	39	
Samarium-154	241,301	12,835	84	
Selenium-74	9,271	77,258	100	5.18
Selenium-76	13,902	6,124	8	
Selenium-77	10,275	5,189	7	
Selenium-78	12,674	2,159	3	
Selenium-80	34,912	2,645	3	
Selenium-82	9,528	5,207	7	

Table 8 (continued)

Isotope	Total sales (mg)	Production requirement (tank h)	Sales/production capability (%)	Production effort (%)
Silicon-28	38,650	1,101	1	
Silicon-29	32,378	24,529	32	
Silicon-30	35,016	38,061	100	2.55
Silver-107	81,034	3,554	100	0.24
Silver-109	63,712	3,005	85	
Strontium-84	16,318	30,558	100	2.05
Strontium-86	50,331	4,793	16	
Strontium-87	43,390	5,840	19	
Strontium-88	324,890	4,118	17	
Sulfur-32	15,462	323	1	
Sulfur-33	5,441	31,270	100	2.10
Sulfur-34	20,707	13,623	44	
Sulfur-36	150	15,000	48	
Tantalum-180	53	22	100	<0.01
Tantalum-181	0	0	0	
Tellurium-120	552	6,815	8	
Tellurium-122	79,507	52,307	67	
Tellurium-123	4,124	5,960	100	0.40
Tellurium-124	319,905	78,026	100	5.23
Tellurium-125	26,904	3,747	63	
Tellurium-126	37,321	2,871	4	
Tellurium-128	116,857	4,443	5	
Tellurium-130	106,124	4,145	5	
Thallium-203	4,932,964	104,291	100	6.99
Thallium-205	94,157	856	1	

Table 8 (continued)

Isotope	Total sales (mg)	Production requirement (tank h)	Sales/production capability (%)	Production effort (%)
Tin-112	56,946	109,512	100	7.34
Tin-114	3,690	10,758	20	
Tin-115	335	1,402	2	
Tin-116	50,891	5,449	10	
Tin-117	142,008	25,773	48	
Tin-118	105,698	7,047	12	
Tin-119	131,318	23,534	42	
Tin-120	107,544	4,519	8	
Tin-122	36,499	12,673	12	
Tin-124	130,566	36,676	33	
Titanium-46	23,630	6,075	32	
Titanium-47	17,902	4,699	24	
Titanium-48	52,882	1,414	7	
Titanium-49	18,795	7,964	41	
Titanium-50	43,711	19,256	100	1.29
Tungsten-180	1,863	1,218	18	
Tungsten-182	209,484	6,037	100	0.40
Tungsten-183	13,805	598	100	0.04
Tungsten-184	200,424	4,998	83	
Tungsten-186	221,117	5,976	90	
Vanadium-50	149	3,386	100	0.23
Vanadium-51	470	46	1	
Ytterbium-168	16,834	64,746	100	4.34
Ytterbium-170	14,329	7,542	23	
Ytterbium-171	22,306	2,535	8	
Ytterbium-172	15,954	1,330	4	
Ytterbium-173	17,534	1,865	5	
Ytterbium-174	42,475	2,321	7	
Ytterbium-176	41,842	6,311	10	

Table 8 (continued)

Isotope	Total sales (mg)	Production requirement (tank h)	Sales/production capability (%)	Production effort (%)
Zinc-64	82,967	3,228	4	
Zinc-66	45,731	2,147	3	
Zinc-67	34,824	14,042	19	
Zinc-68	1,151,262	72,865	100	4.88
Zinc-70	5,598	11,309	16	
Zirconium-90	87,954	6,926	77	
Zirconium-91	14,453	6,098	68	
Zirconium-92	15,413	4,099	46	
Zirconium-94	13,869	3,748	42	
Zirconium-96	3,071	8,953	100	0.60
Total	27,061,058	1,491,981		

Table 9. Annual sales replacement time and surpluses to be generated

Isotope	Inventory on 12/31/84 (mg)	Avg. sales 1980-1984 (mg/year)	Replacement time (tank h)	Surplus in collection (%)
Antimony-121	0	534	19	39
Antimony-123	538	919	31	0
Barium-130	682	53	624	0
Barium-132	192	47	343	45
Barium-134	0	43	21	93
Barium-135	3,700	1,041	253	19
Barium-136	401	1,075	133	57
Barium-137	500	551	54	83
Barium-138	4,909	2,878	64	79
Bromine-79	0	1,702	161	0
Bromine-81	0	919	99	39
Cadmium-106	352	189	170	93
Cadmium-108	0	83	82	97
Cadmium-110	7,733	2,158	216	91
Cadmium-111	1,860	2,056	219	0
Cadmium-112	45,864	43,139	2,307	0
Cadmium-113	0	2,053	220	0
Cadmium-114	245,569	4,620	222	90
Cadmium-116	5,208	1,447	259	90
Calcium-40	66,549	4,090	75	99
Calcium-42	2,386	991	2,263	66
Calcium-43	540	38	346	95
Calcium-44	5,771	2,683	1,607	76
Calcium-46	0	37	6,727	0
Calcium-48	1,811	979	6,276	7
Cerium-136	930	3	31	96
Cerium-138	172	0	0	100
Cerium-140	501	544	183	74

Table 9 (continued)

Isotope	Inventory on 12/31/84 (mg)	Avg. sales 1980-1984 (mg/year)	Replacement time (tank h)	Surplus in collection (%)
Chlorine-35	8,604	3,189	301	0
Chlorine-37	11,623	642	225	25
Chromium-50	9,473	2,453	1,100	17
Chromium-52	7,260	1,073	23	98
Chromium-53	3,314	862	169	87
Chromium-54	2,735	1,225	1,325	0
Copper-63	52,138	32,924	557	0
Copper-65	54,440	14,313	555	0
Dysprosium-156	0	27	794	32
Dysprosium-158	163	62	1,170	0
Dysprosium-160	744	707	431	26
Dysprosium-161	85	2,507	224	62
Dysprosium-162	973	4,998	340	42
Dysprosium-163	1,476	2,220	176	70
Dysprosium-164	584	7,310	522	55
Erbium-162	0	31	178	61
Erbium-164	584	97	103	77
Erbium-166	4,000	2,355	124	45
Erbium-167	588	3,070	229	0
Erbium-168	4,149	3,396	227	0
Erbium-170	3,943	2,901	346	24
Europium-151	0	1,909	102	37
Europium-153	1	2,987	162	0
Gadolinium-152	2	233	1,404	10
Gadolinium-154	1,187	271	192	75
Gadolinium-155	4,757	314	67	91
Gadolinium-156	3,289	1,985	294	62

Table 9 (continued)

Isotope	Inventory on 12/31/84 (mg)	Avg. sales 1980–1984 (mg/year)	Replacement time (tank h)	Surplus in collection (%)
Gadolinium-157	457	416	61	92
Gadolinium-158	3,216	1,342	163	79
Gadolinium-160	96	13,087	1,560	0
Gallium-69	3,579	1,736	72	47
Gallium-71	417	1,796	135	0
Germanium-70	9,617	2,401	372	19
Germanium-72	17,180	1,297	125	73
Germanium-73	8,242	241	95	79
Germanium-74	12,039	6,225	458	0
Germanium-76	4,180	588	310	32
Hafnium-174	144	3	53	81
Hafnium-176	692	84	113	0
Hafnium-177	1,109	464	121	25
Hafnium-178	2,315	333	47	58
Hafnium-179	1,483	583	162	0
Hafnium-180	3,928	776	106	6
Indium-113	0	70	31	0
Indium-115	988	278	5	84
Iridium-191	3,060	838	96	0
Iridium-193	15,687	1,000	58	40
Iron-54	400	6,610	1,801	74
Iron-56	402	30,998	447	94
Iron-57	11	6,507	3,828	45
Iron-58	8	1,624	6,911	0
Lanthanum-138	346	60	170	0
Lanthanum-139	4,896	20	1	99

Table 9 (continued)

Isotope	Inventory on 12/31/84 (mg)	Avg. sales 1980-1984 (mg/year)	Replacement time (tank h)	Surplus in collection (%)
Lead-204	15,502	143	68	94
Lead-206	20,586	3,708	141	82
Lead-207	90,223	7,194	273	0
Lead-208	511,888	47,954	784	0
Lutetium-175	1,866	344	8	99
Lutetium-176	0	1,192	1,028	0
Magnesium-24	3,356	5,329	170	74
Magnesium-25	0	2,917	650	0
Magnesium-26	335	1,762	362	44
Mercury-196	659	21	309	63
Mercury-198	795	151	363	0
Mercury-199	1,937	205	177	79
Mercury-200	1,892	157	91	75
Mercury-201	328	396	388	53
Mercury-202	2,616	173	84	77
Mercury-204	6,494	395	832	0
Molybdenum-92	5,523	2,597	170	84
Molybdenum-94	881	1,570	157	85
Molybdenum-95	8,459	16,170	1,043	0
Molybdenum-96	5,732	4,745	264	75
Molybdenum-97	1,477	2,547	271	74
Molybdenum-98	118,017	1,594	70	93
Molybdenum-100	9,806	5,234	614	41
Neodymium-142	8,757	1,357	103	74
Neodymium-143	4,445	996	157	60
Neodymium-144	1,448	2,407	204	49
Neodymium-145	1,779	1,653	370	7

Table 9 (continued)

Isotope	Inventory on 12/31/84 (mg)	Avg. sales 1980–1984 (mg/year)	Replacement time (tank h)	Surplus in collection (%)
Neodymium-146	3,321	2,074	250	37
Neodymium-148	3,636	1,115	385	52
Neodymium-150	1,502	2,036	795	0
Nickel-58	4,018	52,113	535	66
Nickel-60	12,731	52,129	1,272	20
Nickel-61	3,670	443	259	84
Nickel-62	9,220	8,449	1,588	0
Nickel-64	44	1,422	1,102	31
Osmium-184	34	1	44	89
Osmium-186	91	24	119	56
Osmium-187	513	31	68	51
Osmium-188	733	388	165	38
Osmium-189	190	398	140	0
Osmium-190	8,960	1,471	268	0
Osmium-192	3,512	987	138	66
Palladium-102	0	143	298	0
Palladium-104	8,001	421	80	46
Palladium-105	12,703	757	76	49
Palladium-106	16,202	510	43	71
Palladium-108	13,714	1,553	120	60
Palladium-110	7,320	492	94	68
Platinum-190	37	14	286	9
Platinum-192	278	72	313	0
Platinum-194	3,238	366	32	79
Platinum-195	2,934	670	63	60
Platinum-196	3,471	444	54	65
Platinum-198	2,295	542	255	19

Table 9 (continued)

Isotope	Inventory on 12/31/84 (mg)	Avg. sales 1980-1984 (mg/year)	Replacement time (tank h)	Surplus in collection (%)
Potassium-39	1,103	1,405	95	98
Potassium-40	0	47	5,875	0
Potassium-41	0	519	633	89
Rhenium-185	0	1,709	100	0
Rhenium-187	216	802	25	75
Rubidium-185	2	2,353	77	81
Rubidium-87	2,272	5,230	409	0
Ruthenium-96	1,757	410	622	7
Ruthenium-98	809	20	100	85
Ruthenium-99	5,841	312	190	71
Ruthenium-100	4,971	312	208	69
Ruthenium-101	6,816	1,246	666	0
Ruthenium-102	11,216	835	263	61
Ruthenium-104	9,322	875	369	45
Samarium-144	57	1,100	400	62
Samarium-147	0	2,469	193	64
Samarium-148	7,201	1,432	142	73
Samarium-149	5,137	1,912	168	68
Samarium-150	2,510	1,947	317	40
Samarium-152	3,194	11,677	485	54
Samarium-154	4,301	19,899	1,058	0
Selenium-74	1,731	205	1,708	0
Selenium-76	2,329	1,247	549	68
Selenium-77	269	420	212	88
Selenium-78	76	423	72	96
Selenium-80	480	1,995	151	91
Selenium-82	2,541	605	331	81

Table 9 (continued)

Isotope	Inventory on 12/31/84 (mg)	Avg. sales 1980-1984 (mg/year)	Replacement time (tank h)	Surplus in collection (%)
Silicon-28	1,276	1,867	53	98
Silicon-29	10	3,672	2,782	0
Silicon-30	12	1,885	2,049	26
Silver-107	2,581	8,819	387	0
Silver-109	7,363	7,467	352	9
Strontium-84	1,878	508	951	0
Strontium-86	1,980	2,551	243	74
Strontium-87	10,036	1,662	224	76
Strontium-88	18,939	20,893	265	72
Sulfur-32	3,988	1,055	22	99
Sulfur-33	56	342	1,966	0
Sulfur-34	894	1,004	661	66
Sulfur-36	17	15	1,500	24
Tantalum-180	1	8	4	0
Tantalum-181	0	0	0	100
Tellurium-120	39	16	196	98
Tellurium-122	20,572	497	327	96
Tellurium-123	1,680	264	382	0
Tellurium-124	112,106	35,470	8,651	0
Tellurium-125	4,301	1,690	236	38
Tellurium-126	6,338	3,033	234	97
Tellurium-128	6,369	8,109	309	97
Tellurium-130	26,019	9,133	357	96
Thallium-203	988,364	723,558	15,298	0
Thallium-205	13,812	2,979	3	100

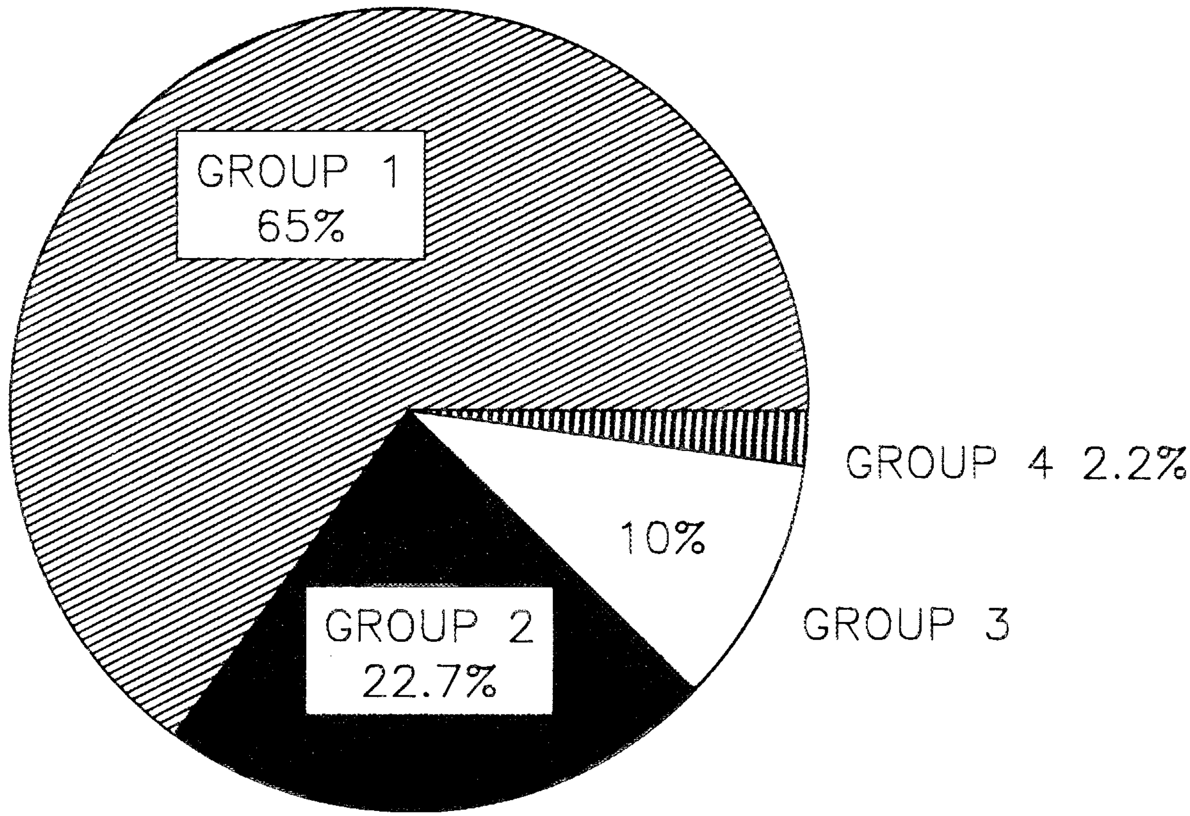
Table 9 (continued)

Isotope	Inventory on 12/31/84 (mg)	Avg. sales 1980-1984 (mg/year)	Replacement time (tank h)	Surplus in collection (%)
Tin-112	5,931	1,948	3,746	6
Tin-114	239	221	645	62
Tin-115	651	8	34	99
Tin-116	5,241	2,450	263	85
Tin-117	5,263	12,513	2,271	0
Tin-118	10,841	4,265	285	83
Tin-119	1,700	6,904	1,238	45
Tin-120	513	4,244	179	90
Tin-122	2,157	2,345	815	80
Tin-124	649	14,184	3,985	0
Titanium-46	0	2,113	544	41
Titanium-47	2,041	536	42	
Titanium-48	1,453	2,710	73	92
Titanium-49	0	2,167	919	0
Titanium-50	0	729	322	65
Tungsten-180	508	28	19	75
Tungsten-182	3,341	1,096	32	0
Tungsten-183	0	992	43	0
Tungsten-184	3,861	931	24	25
Tungsten-186	1,326	2,130	58	23
Vanadium-50	24	7	160	0
Vanadium-51	0	0	0	100
Ytterbium-168	2,306	747	2,873	0
Ytterbium-170	1,257	225	119	92
Ytterbium-171	8,969	1,549	176	88
Ytterbium-172	7,612	649	54	96
Ytterbium-173	4,839	879	94	93
Ytterbium-174	6,525	1,465	80	94
Ytterbium-176	5,501	2,947	445	85

Table 9 (continued)

Isotope	Inventory on 12/31/84 (mg)	Avg. sales 1980-1984 (mg/year)	Replacement time (tank h)	Surplus in collection (%)
Zinc-64	7,949	3,541	138	98
Zinc-66	20,137	3,956	186	98
Zinc-67	11,292	3,341	1,347	85
Zinc-68	56,263	143,358	9,074	0
Zinc-70	2,648	602	1,216	87
Zirconium-90	1,938	4,947	390	0
Zirconium-91	4,811	301	127	0
Zirconium-92	929	731	195	50
Zirconium-94	213	873	236	54
Zirconium-96	1,705	62	181	65
Total	3,133,978			

SUMMARY OF SEPARATION EFFORTS
1945 TO 1985



SUBDIVISION OF SEPARATION EFFORT

Fig. 1.

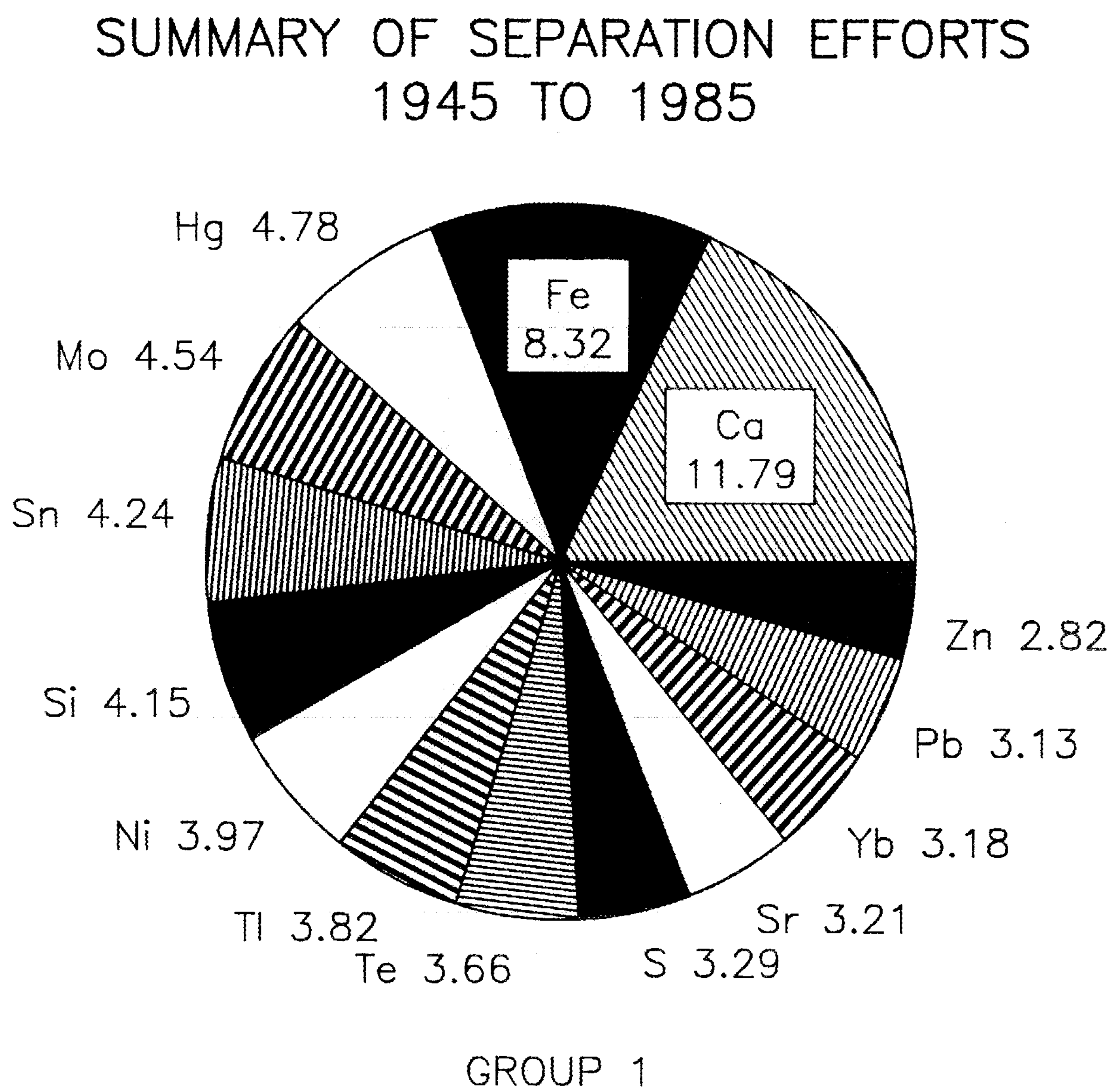


Fig. 2.

Group represents 64.90% of total effort.

SUMMARY OF SEPARATION EFFORTS 1945 TO 1985

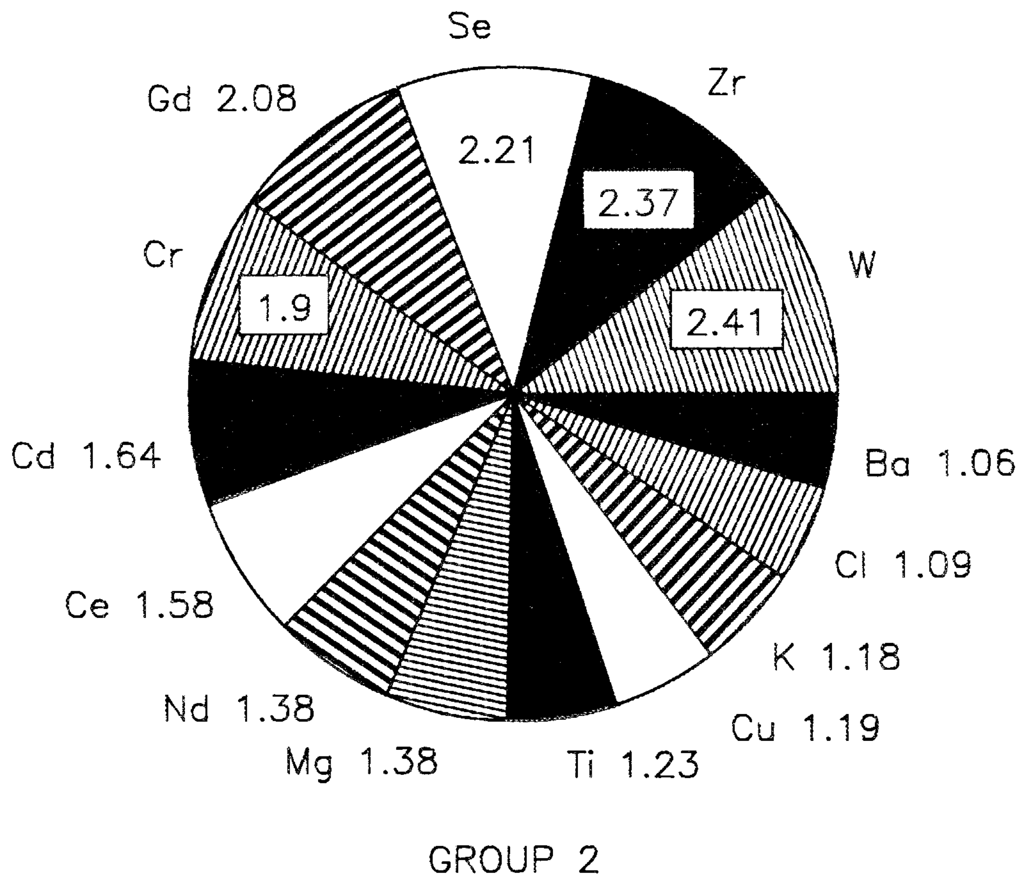
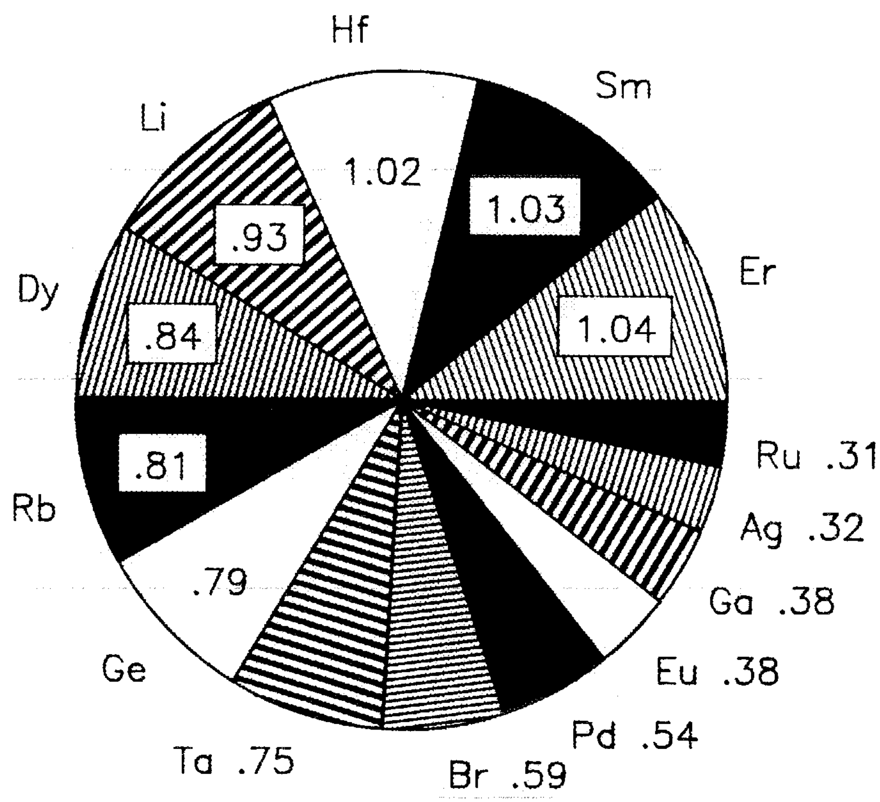


Fig. 3.

Group 2 represents 22.7% of total effort.

SUMMARY OF SEPARATION EFFORTS
1945 TO 1985



GROUP 3

Fig. 4.

Group represents 10.02% of total effort.

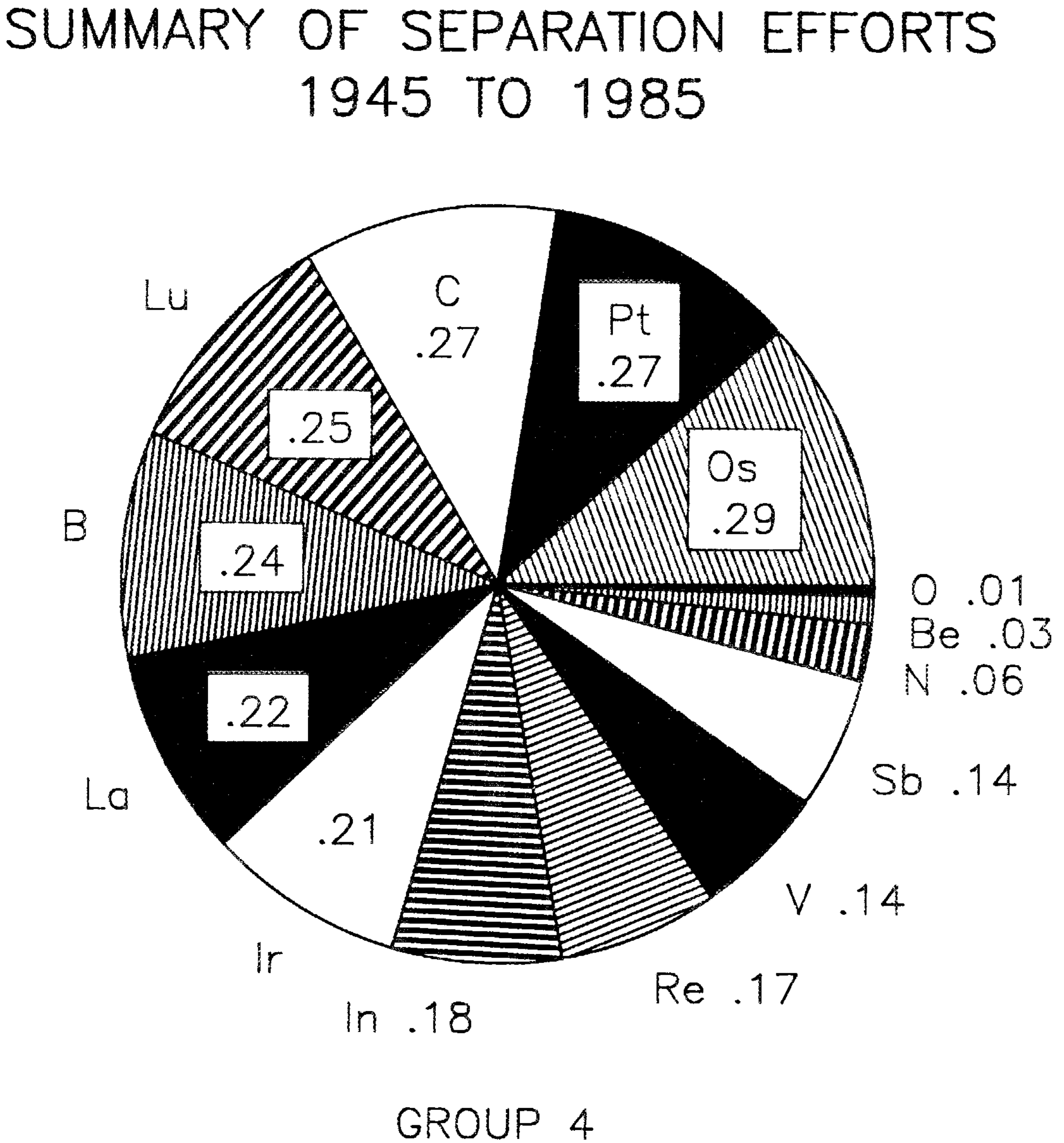


Fig. 5.

Group represents 2.19% of total effort.

Fig. 6.

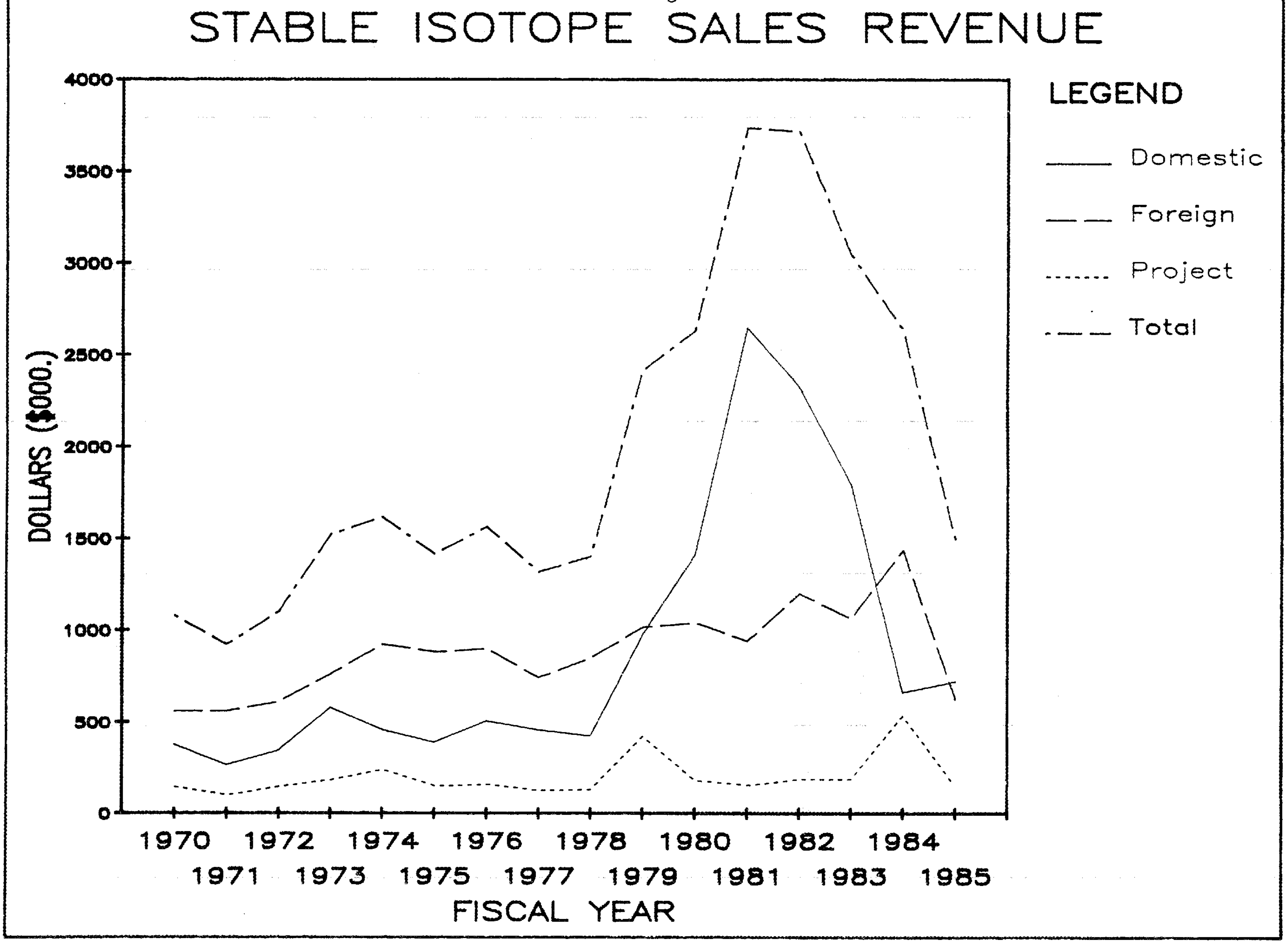
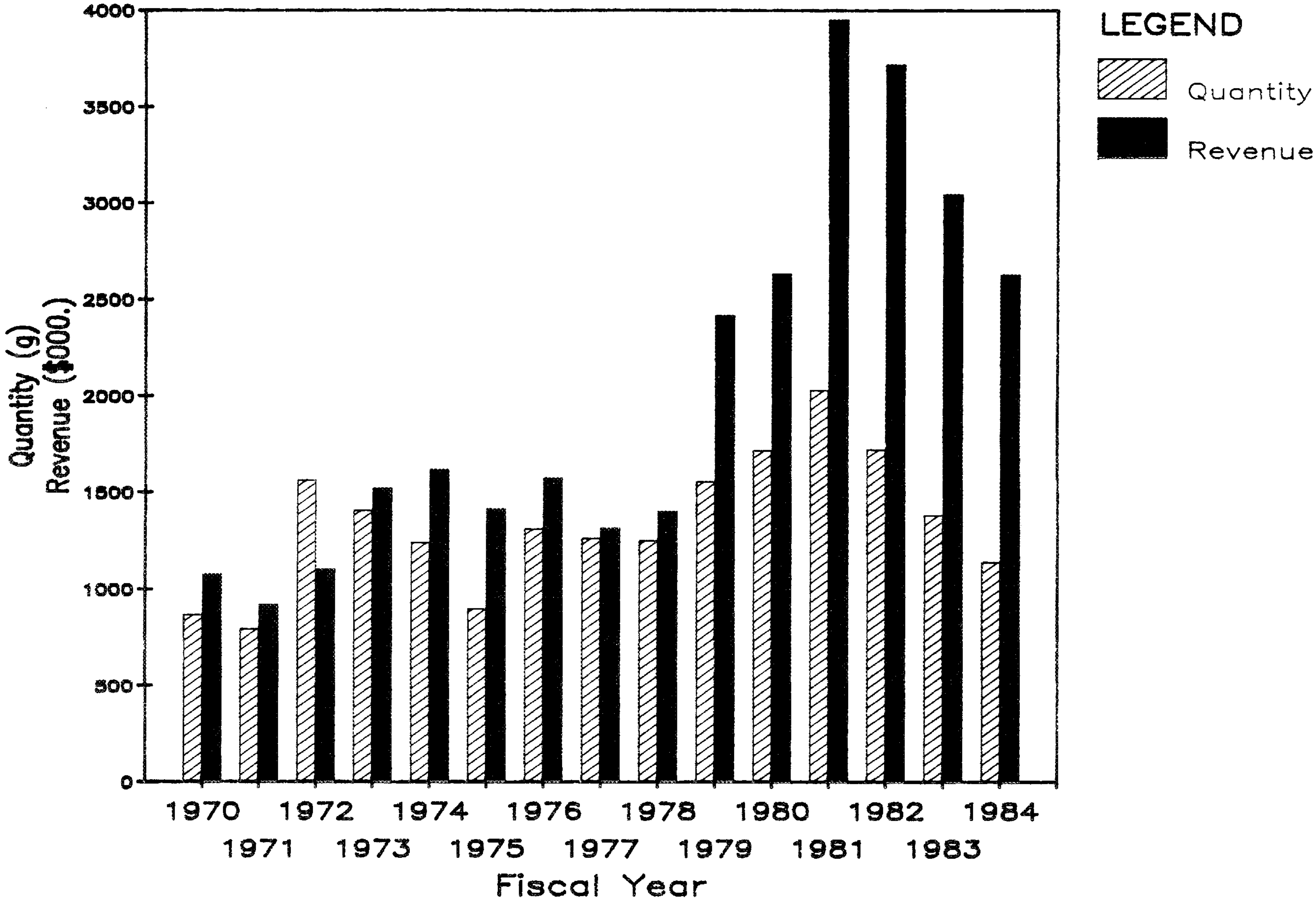

STABLE ISOTOPE SALES REVENUE
DOLLARS ($000.)
4000
3500
3000
2500
2000
1500
1000
500
0
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
FISCAL YEAR
LEGEND
Domestic
Foreign
Project
Total

Fig. 7.

STABLE ISOTOPE SALES AND REVENUE



APPENDICES

Appendix A

Table. A-1. Prices of separated isotopes (1954 vs 1984)

Isotope	1954 Purity (at. %)	1954 Price ($/mg)	1984 Price[a] ($/mg)
Antimony-121	97.7	6.00	1.35
Antimony-123	96.7	5.00	1.30
Barium-130	27.5	80.00	12.50
Barium-132	12.0	25.00	1.35
Barium-134	50.8	5.00	29.70
Barium-135	67.3	2.00	0.75
Barium-136	50.0	1.25	0.25
Barium-137	43.6	1.00	0.15
Barium-138	97.4	0.25	0.25
Bromine-79	87.0	25.00	0.60
Bromine-81	96.8	20.00	0.80
Cadmium-106	32.9	7.50	2.95
Cadmium-108	14.2	2.50	0.05
Cadmium-110	70.0	1.00	1.10
Cadmium-111	64.5	1.00	1.05
Cadmium-112	83.5	0.50	0.35
Cadmium-113	54.1	0.75	1.45
Cadmium-114	94.2	0.75	0.40
Cadmium-116	71.2	2.25	1.85
Calcium-40	99.9	0.35	0.70
Calcium-42	82.5	50.00	13.30
Calcium-43	68.0	75.00	233.50
Calcium-44	98.0	8.50	3.35
Calcium-46	–	–	–
Calcium-48	7.5	2.00	1.45

Table A-1 (continued)

Isotope	1954 Purity (at. %)	1954 Price ($/mg)	1984 Price[a] ($/mg)
Cerium-136	30.0	60.00	27.45
Cerium-138	13.1	20.00	7.55
Cerium-140	99.7	0.50	0.05
Cerium-142	90.1	3.00	1.75
Chlorine-35	95.7	0.75	0.95
Chlorine-37	66.3	1.50	3.65
Chromium-50	88.3	10.00	4.50
Chromium-52	98.8	0.25	0.80
Chromium-53	90.1	2.50	2.15
Chromium-54	83.1	10.00	10.20
Copper-63	99.9	0.70	0.75
Copper-65	98.2	0.85	1.70
Gadolinium-152	15.0	20.00	2.65
Gadolinium-154	33.2	5.00	0.60
Gadolinium-155	72.3	1.00	1.06
Gadolinium-156	80.2	1.00	0.55
Gadolinium-157	69.7	1.00	0.70
Gadolinium-158	92.9	1.50	0.60
Gadolinium-160	95.4	1.25	0.85
Gallium-69	98.4	0.75	0.55
Gallium-71	98.1	1.25	1.00
Germanium-70	91.4	0.75	2.70
Germanium-72	94.9	0.50	1.55
Germanium-73	78.0	2.00	4.90
Germanium-74	95.8	0.50	2.05
Germanium-76	81.0	1.50	6.75

Table A-1 (continued)

Isotope	1954 Purity (at. %)	1954 Price ($/mg)	1984 Price[a] ($/mg)
Hafnium-174	–	–	–
Hafnium-176	59.5	6.00	10.65
Hafnium-177	59.1	3.00	0.95
Hafnium-178	84.8	2.00	1.10
Hafnium-179	53.3	2.75	0.30
Hafnium-180	93.3	1.50	1.45
Indium-113	65.4	25.00	6.10
Indium-115	99.6	0.75	0.50
Iridium-191	85.9	25.00	2.95
Iridium-193	89.1	20.00	1.70
Iron-54	96.7	6.00	1.80
Iron-56	99.8	0.20	0.10
Iron-57	79.4	7.00	6.95
Iron-58	78.7	45.00	17.35
Lanthanum-138	1.7	40.00	2.60
Lanthanum-139	99.9	1.00	1.00
Lead-204	25.7	5.00	1.05
Lead-206	77.9	1.50	0.85
Lead-207	66.8	1.75	0.55
Lead-208	96.6	1.00	0.60
Magnesium-24	99.6	0.85	0.35
Magnesium-25	92.3	3.50	1.75
Magnesium-26	96.2	4.00	4.30

Table A-1 (continued)

Isotope	1954 Purity (at. %)	1954 Price ($/mg)	1984 Price[a] ($/mg)
Mercury-196	8.4	450.00	24.30
Mercury-198	79.1	10.00	15.35
Mercury-199	73.1	17.50	13.25
Mercury-200	91.4	6.00	24.25
Mercury-201	71.8	30.00	13.40
Mercury-202	98.3	5.00	15.95
Mercury-204	89.2	20.00	19.70
Molybdenum- 92	95.5	1.25	0.35
Molybdenum- 94	84.9	2.25	0.40
Molybdenum- 95	91.3	1.25	0.25
Molybdenum- 96	92.0	1.00	0.25
Molybdenum- 97	89.6	1.75	0.40
Molybdenum- 98	95.2	1.00	1.40
Molybdenum-100	90.2	1.75	0.45
Neodymium-142	93.9	0.75	1.70
Neodymium-143	83.9	1.50	0.65
Neodymium-144	95.7	1.00	0.35
Neodymium-145	78.6	2.00	0.85
Neodymium-146	95.6	1.50	0.45
Neodymium-148	89.9	6.00	0.90
Neodymium-150	94.8	4.00	1.80
Nickel-58	99.9	0.25	0.35
Nickel-60	98.5	0.50	0.25
Nickel-61	80.4	20.00	11.85
Nickel-62	96.8	5.00	8.70
Nickel-64	85.1	35.00	12.50

Table A-1 (continued)

Isotope	1954 Purity (at. %)	1954 Price ($/mg)	1984 Price[a] ($/mg)
Palladium-102	35.2	20.00	9.60
Palladium-104	63.2	4.00	1.60
Palladium-105	78.2	6.00	1.45
Palladium-106	82.3	2.50	1.25
Palladium-108	94.2	2.00	1.55
Palladium-110	91.4	4.00	3.05
Platinum-190	0.8	40.00	6.25
Platinum-192	13.9	25.00	1.20
Platinum-194	65.1	1.25	2.00
Platinum-195	60.1	4.00	1.90
Platinum-196	65.9	2.00	2.05
Platinum-198	61.0	20.00	3.10
Potassium-39	99.9	1.00	0.35
Potassium-40	6.2	400.00	1.20
Potassium-41	99.2	15.00	6.35
Rhenium-185	85.4	1.50	0.50
Rhenium-187	98.2	1.75	0.35
Rubidium-85	96.0	5.00	1.65
Rubidium-87	89.6	6.00	3.50
Ruthenium- 96	95.5	20.00	11.20
Ruthenium- 98	–	–	–
Ruthenium- 99	–	–	–
Ruthenium-100	–	–	–
Ruthenium-101	–	–	–
Ruthenium-102	94.2	10.00	2.25
Ruthenium-104	–	–	–

Table A-1 (continued)

Isotope	1954 Purity (at. %)	1954 Price ($/mg)	1984 Price[a] ($/mg)
Samarium-144	58.9	5.00	4.90
Samarium-147	85.1	1.50	1.75
Samarium-148	76.0	1.50	0.50
Samarium-149	81.5	1.50	0.20
Samarium-150	74.1	3.00	0.30
Samarium-152	93.9	0.75	0.60
Samarium-154	99.1	1.25	1.30
Selenium-74	18.0	25.00	9.10
Selenium-76	88.5	9.00	3.80
Selenium-77	86.6	10.00	10.50
Selenium-78	96.6	3.00	4.40
Selenium-80	98.4	1.50	1.00
Selenium-82	89.9	11.00	33.95
Silicon-28	99.4	0.85	0.85
Silicon-29	80.8	17.50	2.00
Silicon-30	64.0	25.00	2.30
Silver-107	90.3	3.50	0.40
Silver-109	99.5	1.50	0.55
Strontium-84	46.0	20.00	18.65
Strontium-86	89.0	4.25	0.30
Strontium-87	42.8	1.50	0.15
Strontium-88	99.7	0.75	0.40
Sulfur-32	98.5	1.50	0.50
Sulfur-33	5.5	10.00	0.30
Sulfur-34	14.9	12.00	0.10
Sulfur-36	0.9	200.00	28.10

Table A-1 (continued)

Isotope	1954 Purity (at. %)	1954 Price ($/mg)	1984 Price[a] ($/mg)
Tellurium-120	22.3	125.00	11.70
Tellurium-122	86.3	12.50	15.10
Tellurium-123	60.9	25.00	13.35
Tellurium-124	83.9	7.00	7.75
Tellurium-125	87.9	3.00	6.00
Tellurium-126	95.4	1.00	1.50
Tellurium-128	96.5	0.75	1.10
Tellurium-130	97.8	0.75	0.90
Thallium-203	75.6	12.50	1.05
Thallium-205	95.2	5.00	0.45
Tin-112	58.9	15.00	11.50
Tin-114	50.0	35.00	10.75
Tin-115	14.0	10.00	18.85
Tin-116	90.9	0.75	0.35
Tin-117	77.1	1.00	0.35
Tin-118	95.9	0.50	1.05
Tin-119	79.8	0.75	0.30
Tin-120	98.2	0.25	0.20
Tin-122	88.9	1.75	0.75
Tin-124	95.0	1.75	0.50
Titanium-46	84.4	2.50	1.15
Titanium-47	82.8	1.25	1.25
Titanium-48	99.2	0.35	0.35
Titanium-49	79.4	3.25	1.60
Titanium-50	81.4	3.50	2.25

Table A-1 (continued)

Isotope	1954 Purity (at. %)	1954 Price ($/mg)	1984 Price[a] ($/mg)
Tungsten-180	7.0	100.00	5.75
Tungsten-182	94.3	1.25	0.30
Tungsten-183	86.2	1.50	0.40
Tungsten-184	95.7	1.00	0.40
Tungsten-186	97.9	1.00	0.45
Vanadium-50	22.8	60.00	52.50
Vanadium-51	99.9	0.75	-
Zinc-64	93.1	0.60	0.65
Zinc-66	93.8	0.85	1.55
Zinc-67	60.5	2.75	4.30
Zinc-68	95.5	0.80	2.30
Zinc-70	32.9	4.50	6.85
Zirconium-90	98.7	0.75	1.00
Zirconium-91	86.6	2.75	13.50
Zirconium-92	95.4	1.75	1.95
Zirconium-94	-	-	-
Zirconium-96	-	-	-

[a]Based on current catalog base price and purity of 1954 material.

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P. S. Baker, F. R. Duncan, and H. B. Greene, "Preparation of High Purity Lithium Metal by Vacuum Distillation," Science 118, 778-80 (1953).

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L. O. Love, "Developments in the ORNL Electromagnetic Separation Program," Proceedings of the 8th International Electromagnetic Isotope Separators Conference, Skovde, Sweden, ed. G. Andersson and G. Holmen, 1973, pp. 6-16.

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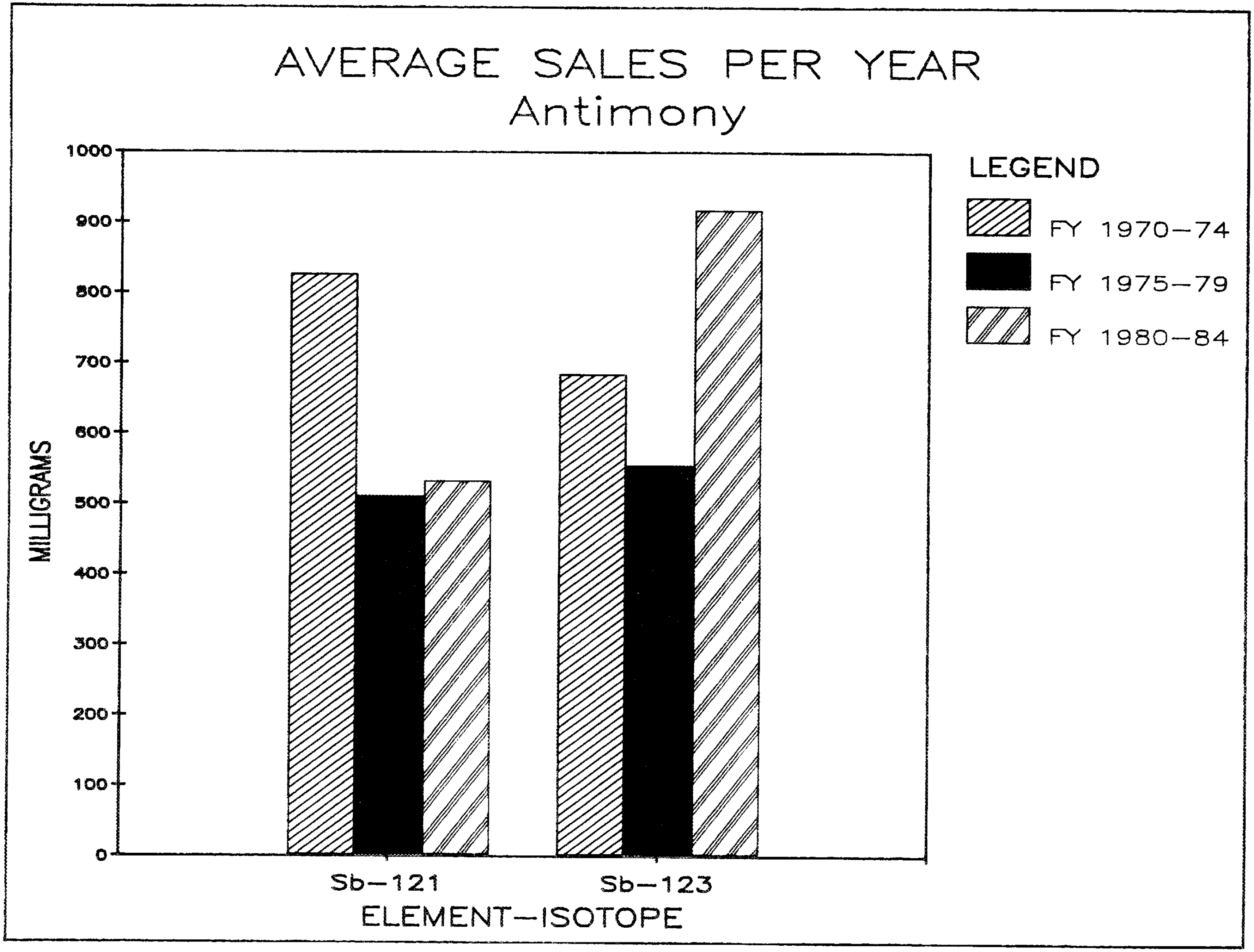
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900
800
700
600
500
400
300
200
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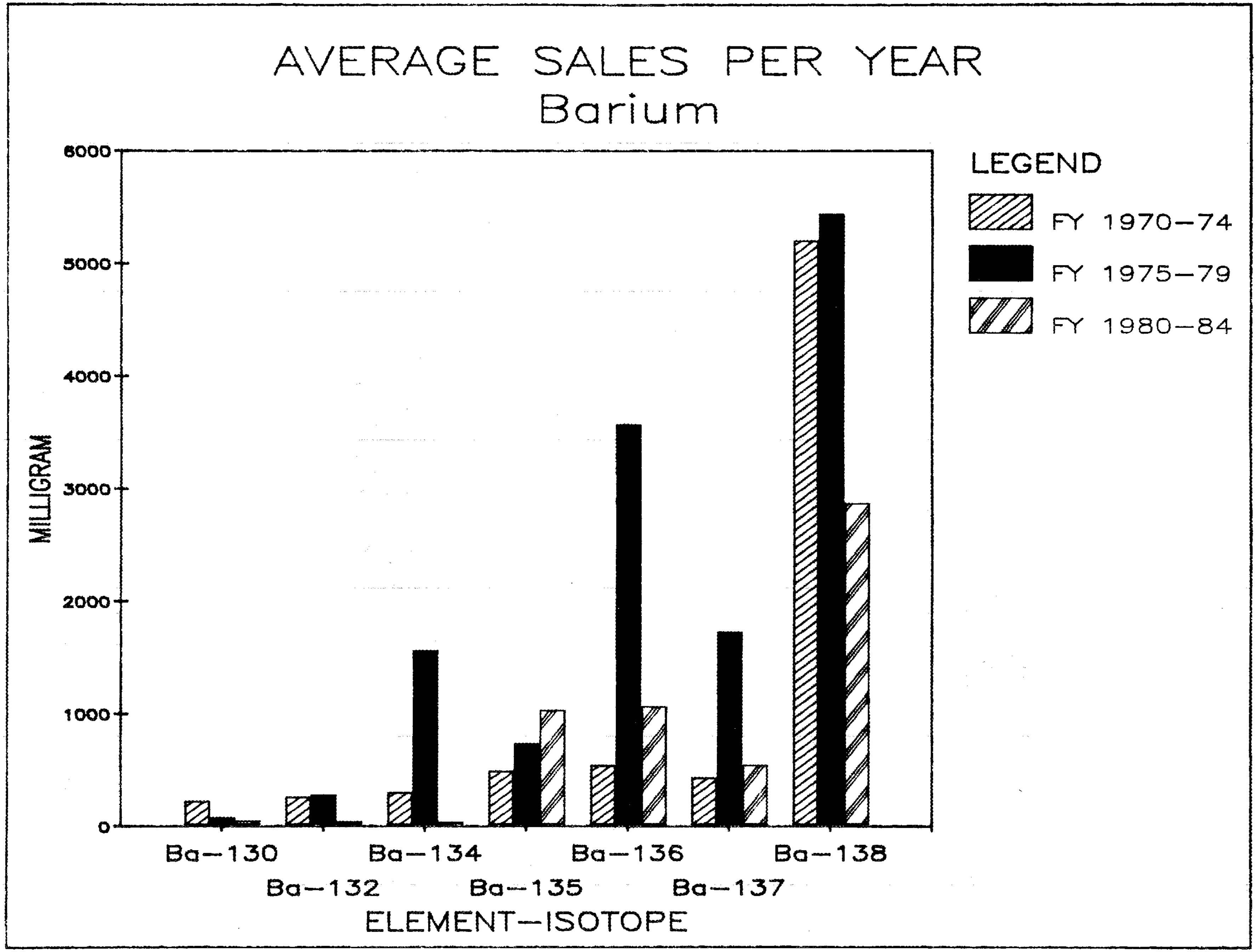
Sb-123
ELEMENT-ISOTOPE
LEGEND
FY 1970-74
FY 1975-79
FY 1980-84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LEGEND
FY 1970–74
FY 1975–79
FY 1980–84
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Ba–136
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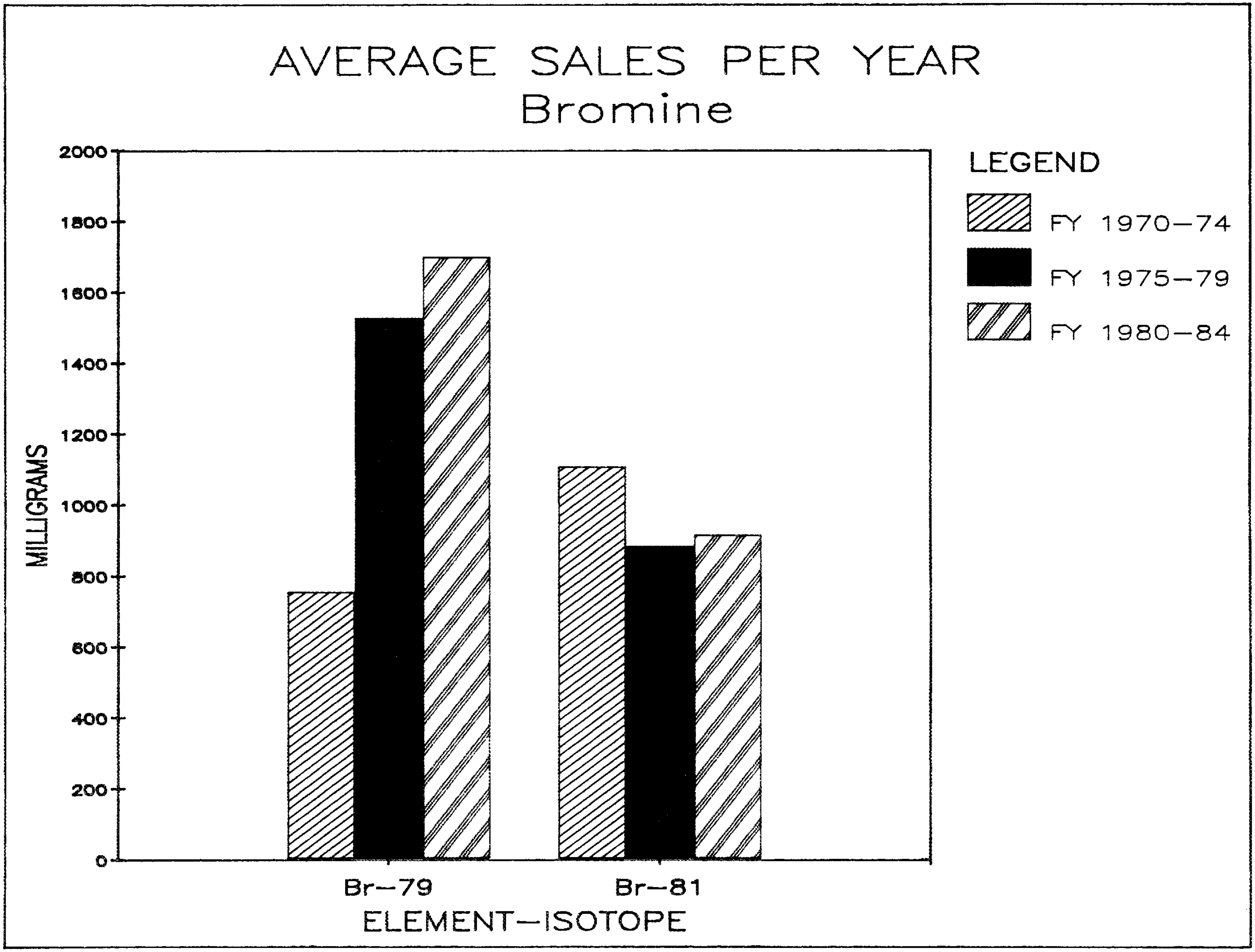
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LEGEND
FY 1970-74
FY 1975-79
FY 1980-84
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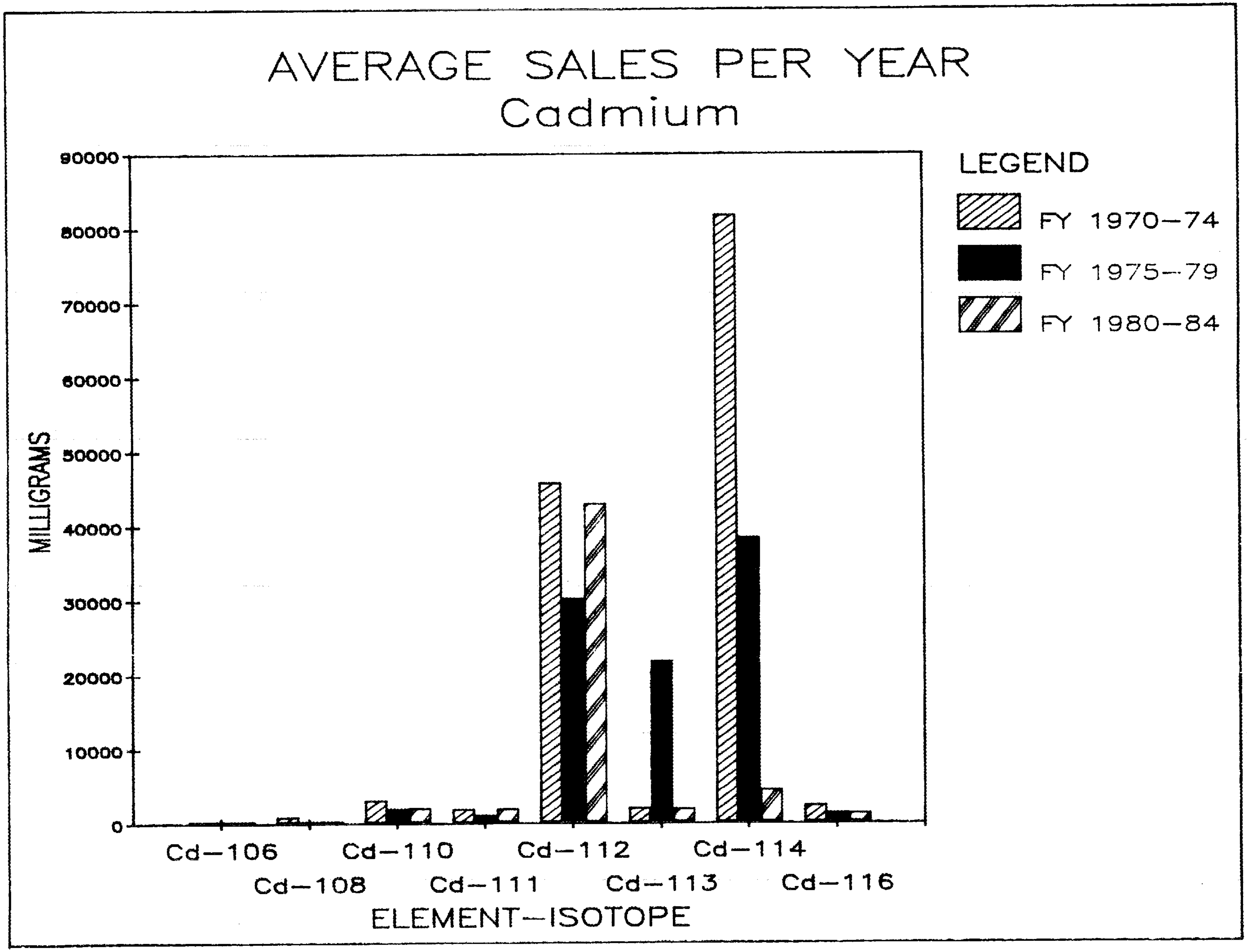
Br-79
Br-81
ELEMENT-ISOTOPE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Cadmium
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FY 1970–74
FY 1975–79
FY 1980–84
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50000
40000
30000
20000
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Cd–111
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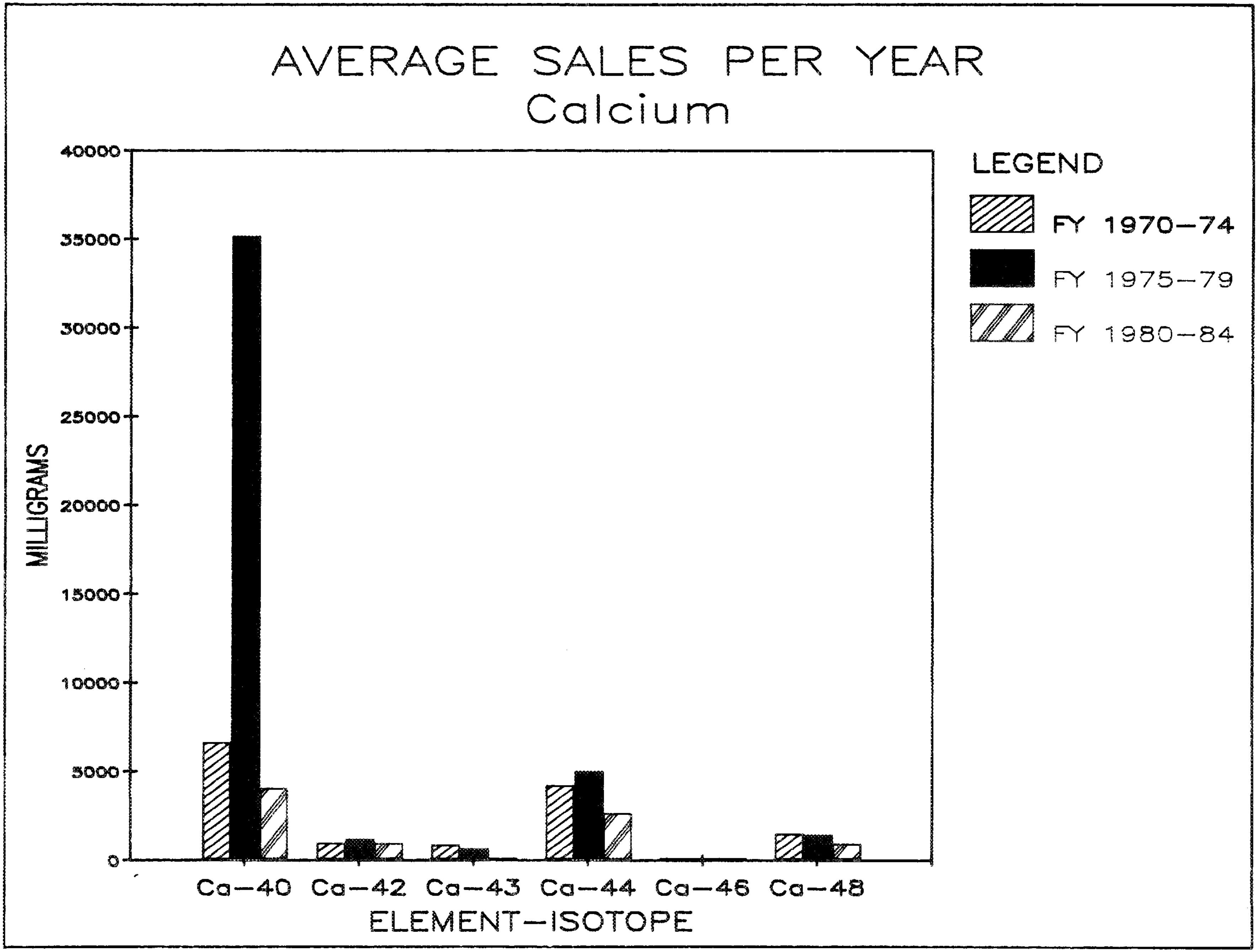
ELEMENT–ISOTOPE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30000
25000
20000
15000
10000
5000
0
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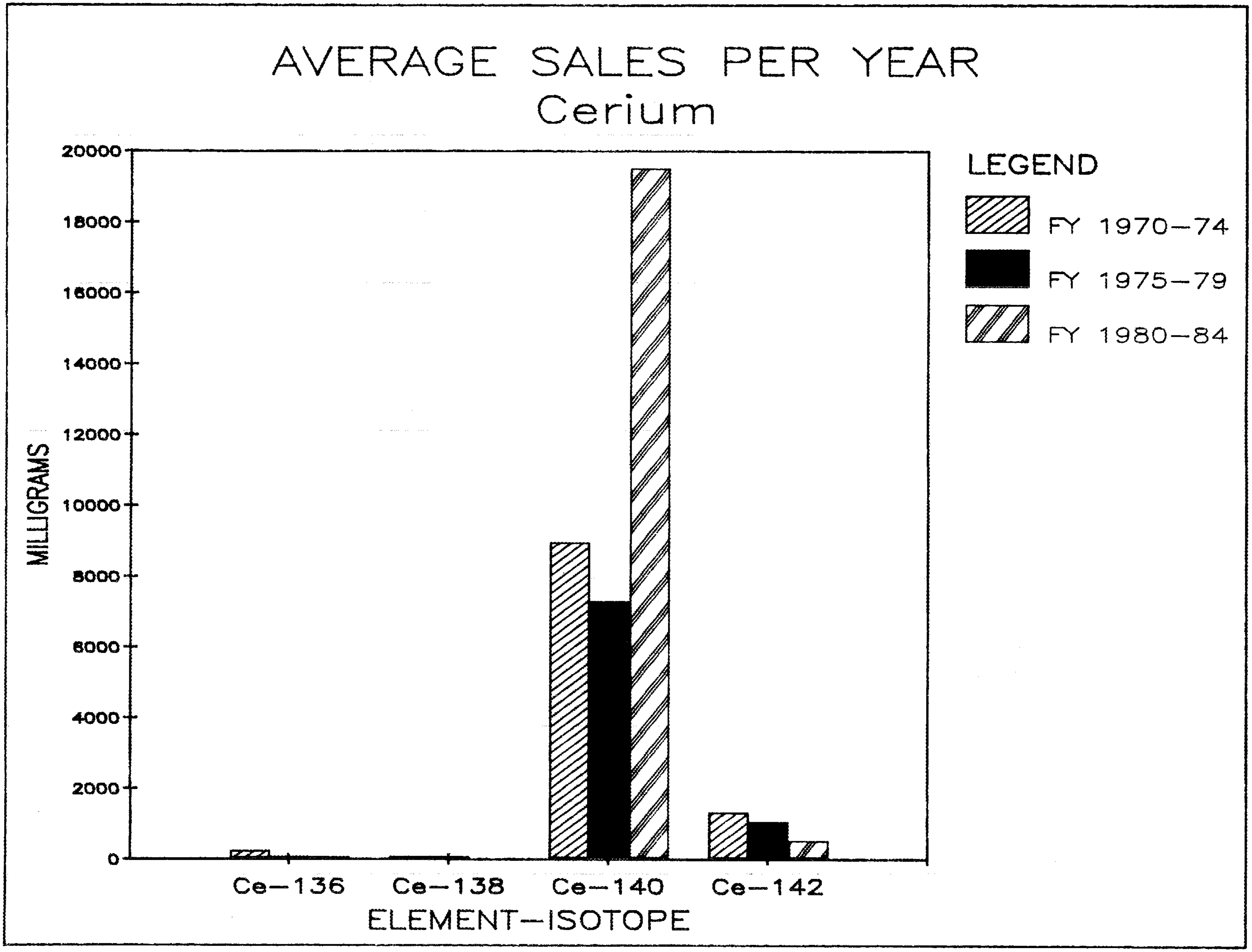
Ca-42
Ca-43
Ca-44
Ca-46
Ca-48
ELEMENT-ISOTOPE
LEGEND
FY 1970-74
FY 1975-79
FY 1980-84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LEGEND
FY 1970-74
FY 1975-79
FY 1980-84
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12000
14000
16000
18000
20000
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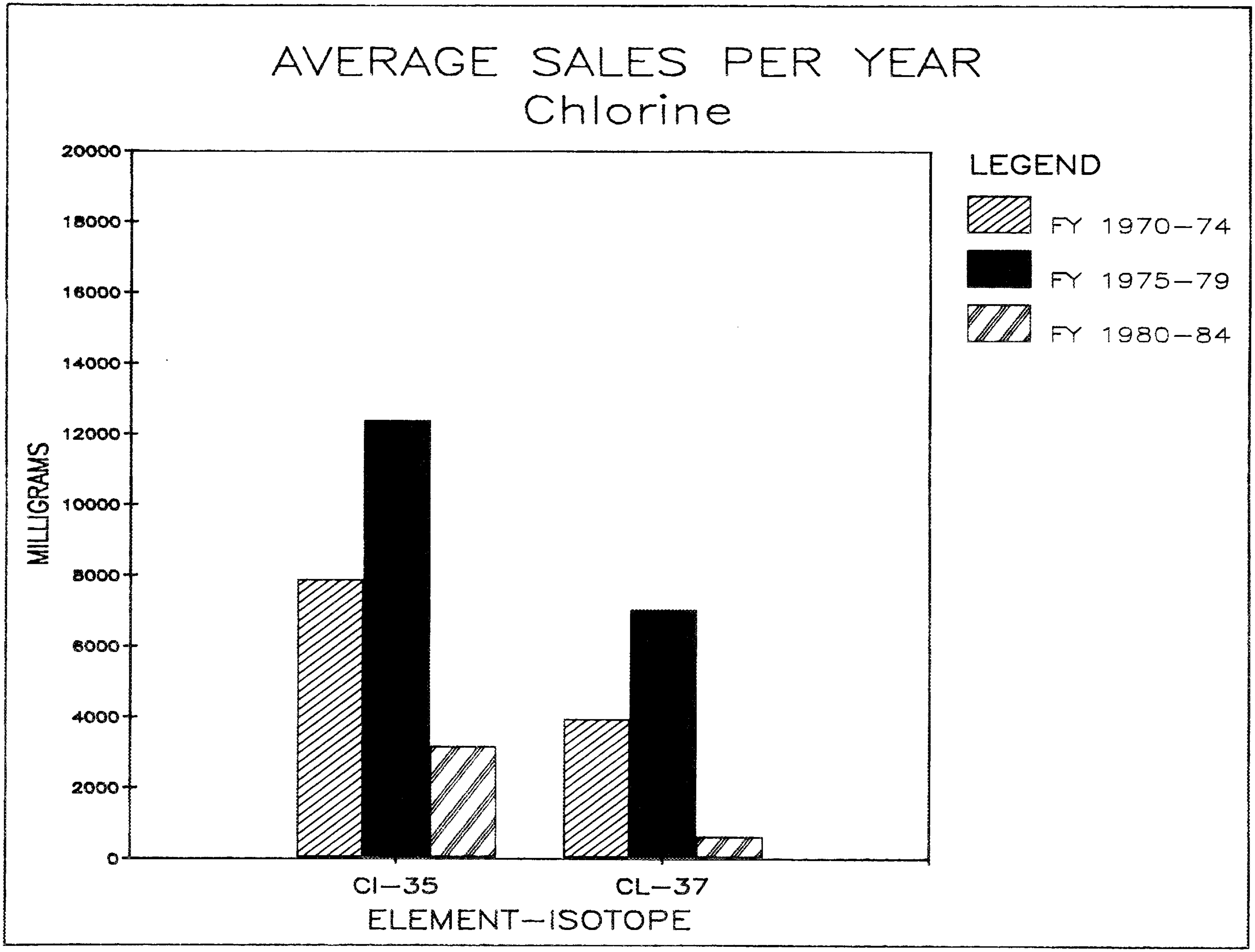
Ce-138
Ce-140
Ce-142
ELEMENT-ISOTOPE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14000
12000
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ELEMENT–ISOTOPE
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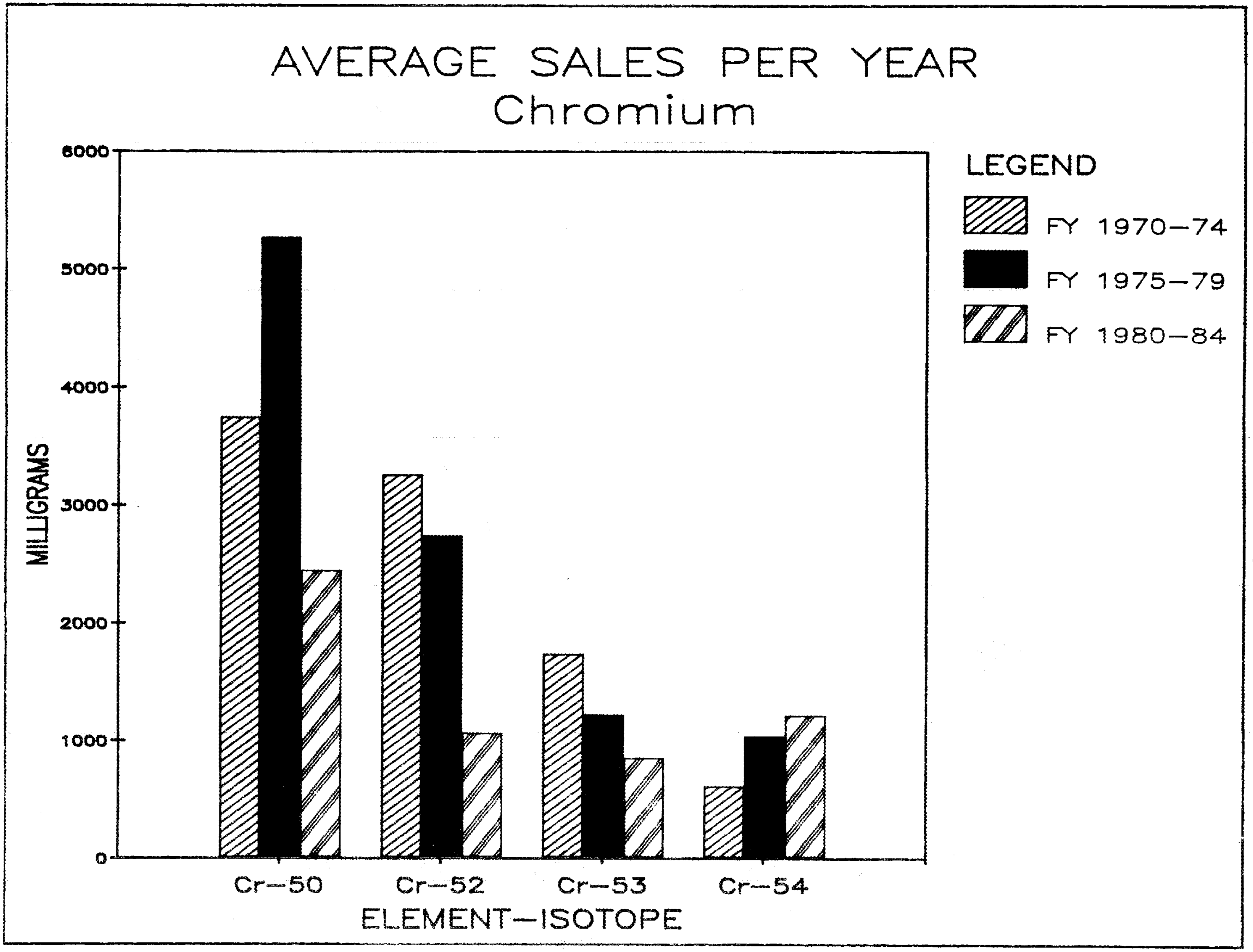
FY 1970–74
FY 1975–79
FY 1980–84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5000
4000
3000
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Cr-52
Cr-53
Cr-54
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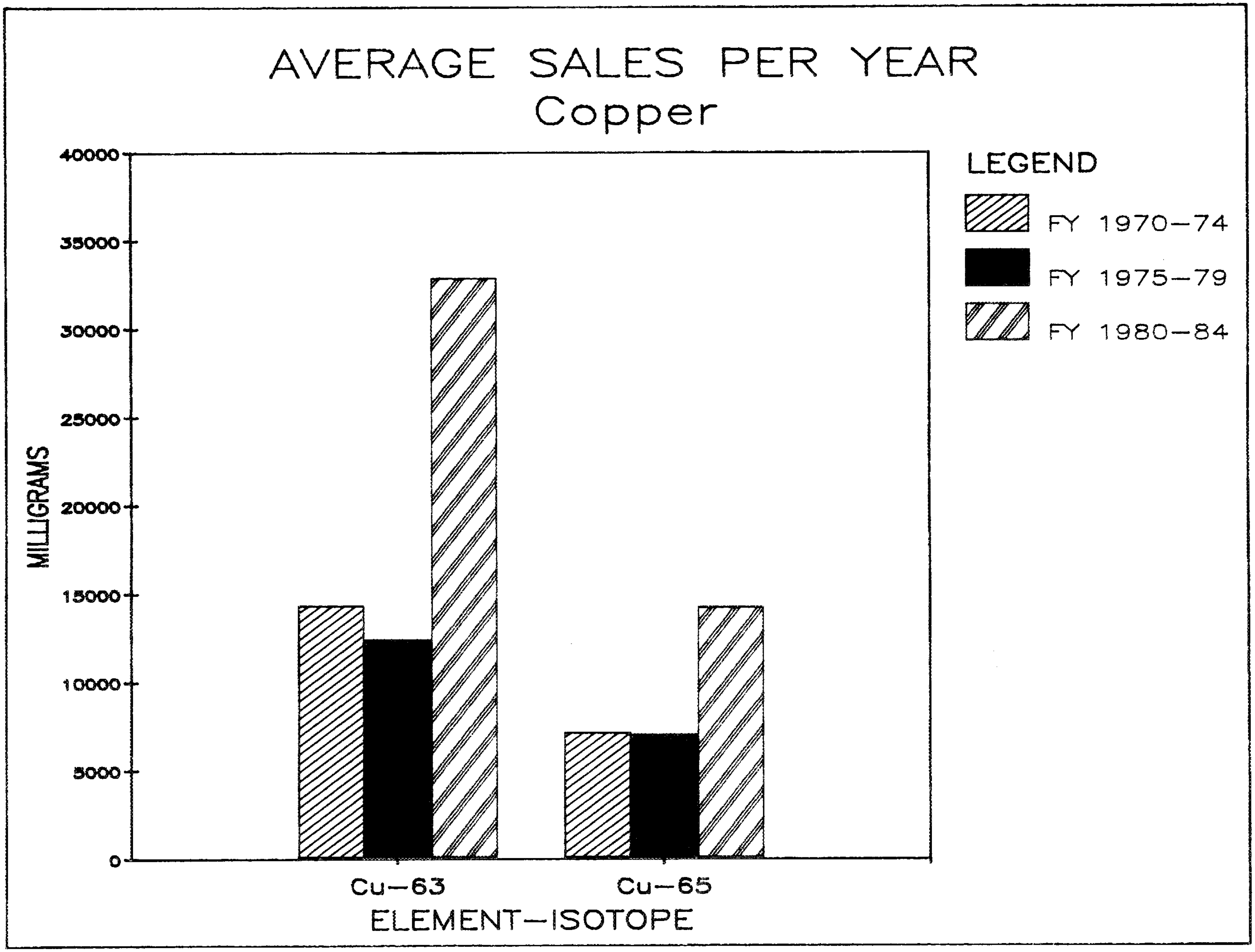
LEGEND
FY 1970-74
FY 1975-79
FY 1980-84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LEGEND
FY 1970-74
FY 1975-79
FY 1980-84
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15000
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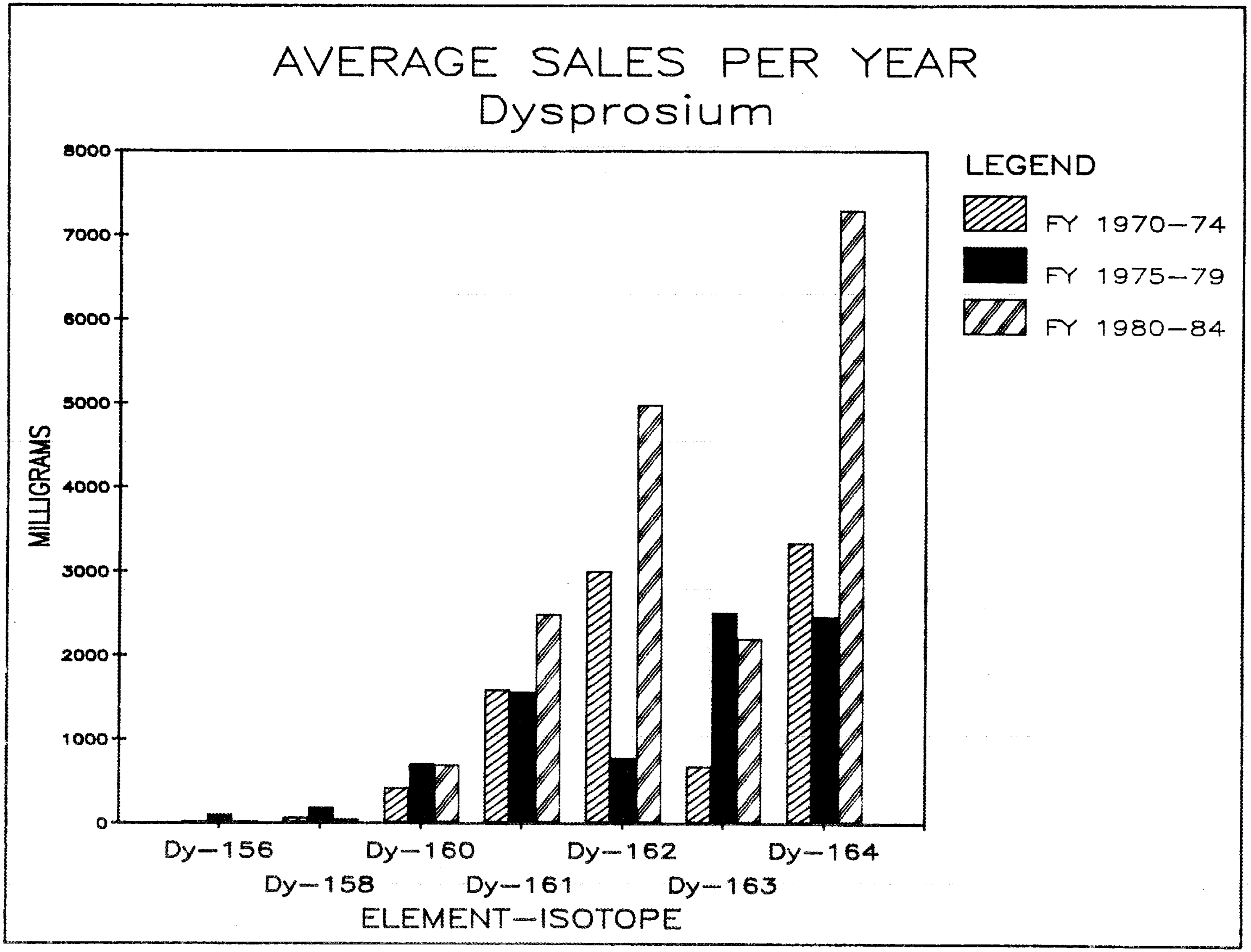
0
Cu-63
Cu-65
ELEMENT-ISOTOPE



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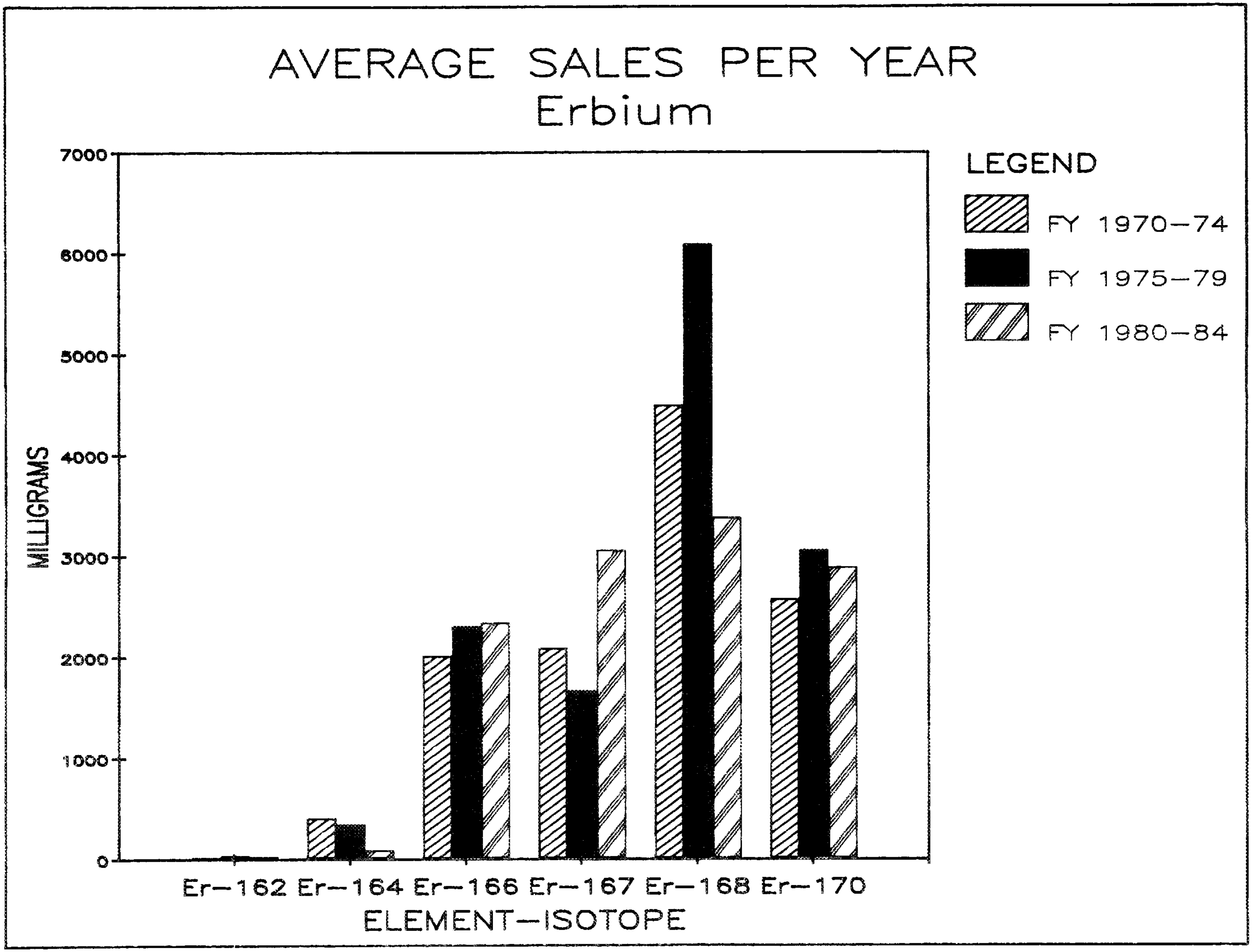
6000
5000
4000
3000
2000
1000
0
Dy-156
Dy-158
Dy-160
Dy-161
Dy-162
Dy-163
Dy-164
ELEMENT-ISOTOPE
LEGEND
FY 1970-74
FY 1975-79
FY 1980-84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LEGEND
FY 1970-74
FY 1975-79
FY 1980-84
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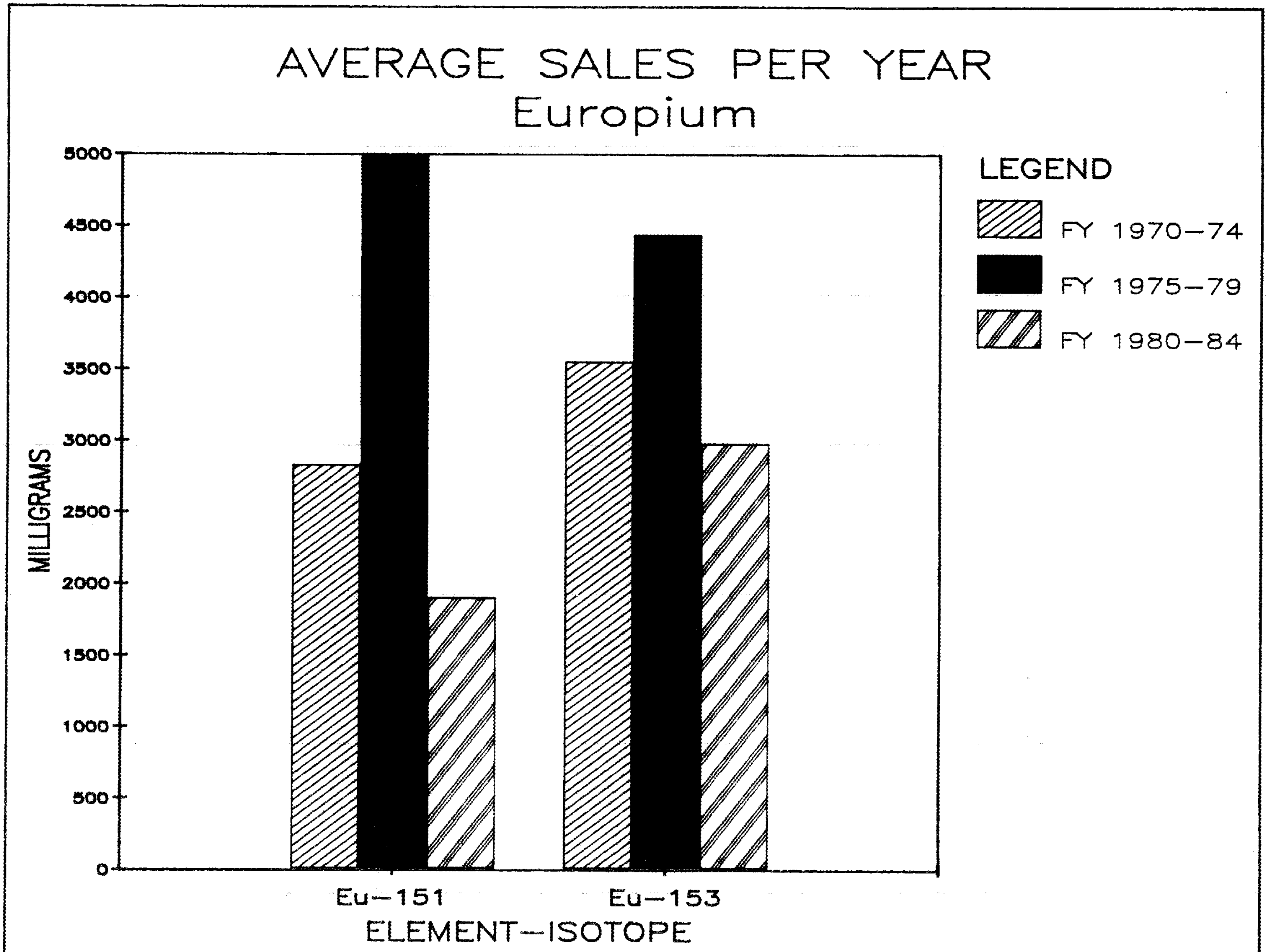
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4000
3500
3000
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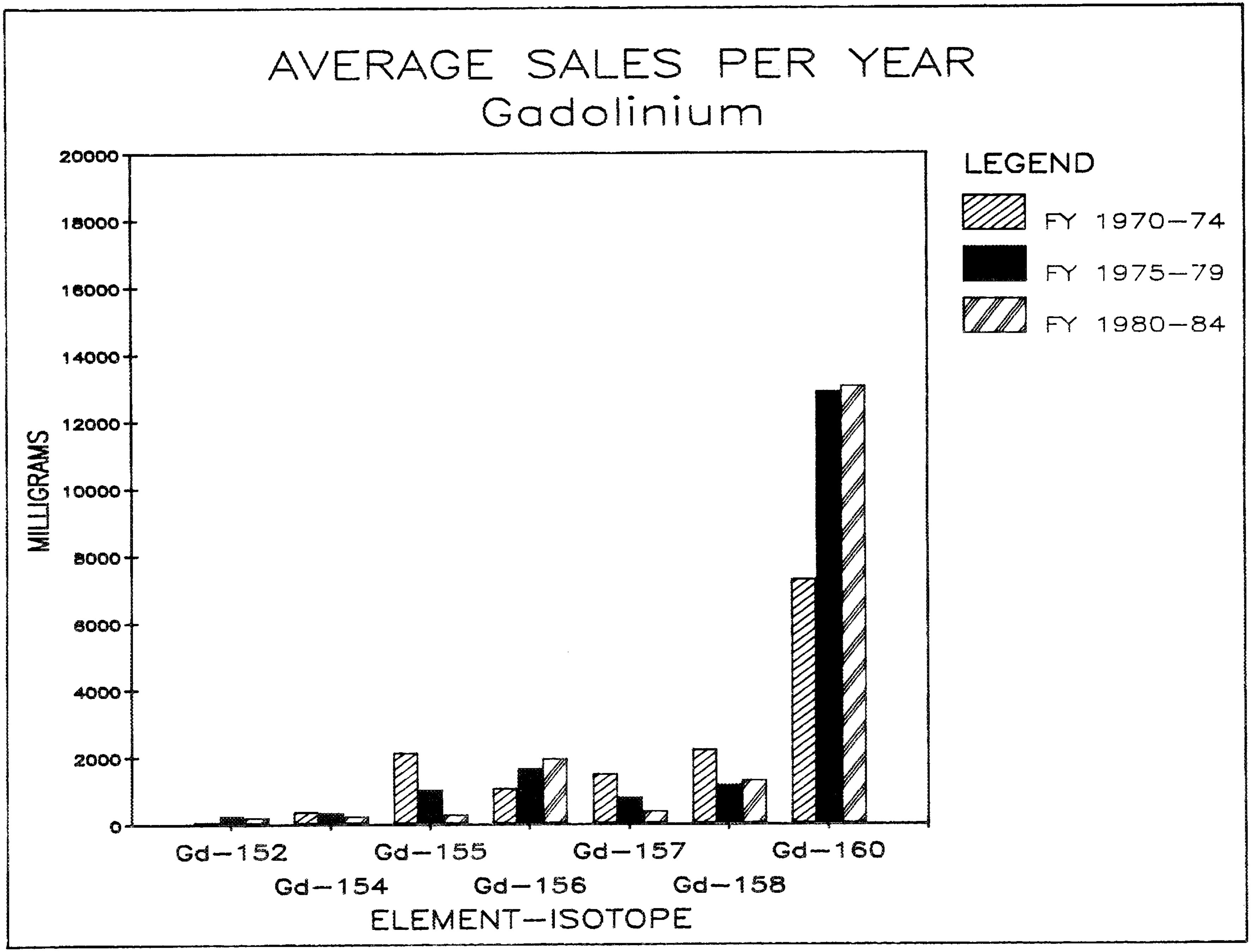
FY 1970-74
FY 1975-79
FY 1980-84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FY 1970-74
FY 1975-79
FY 1980-84
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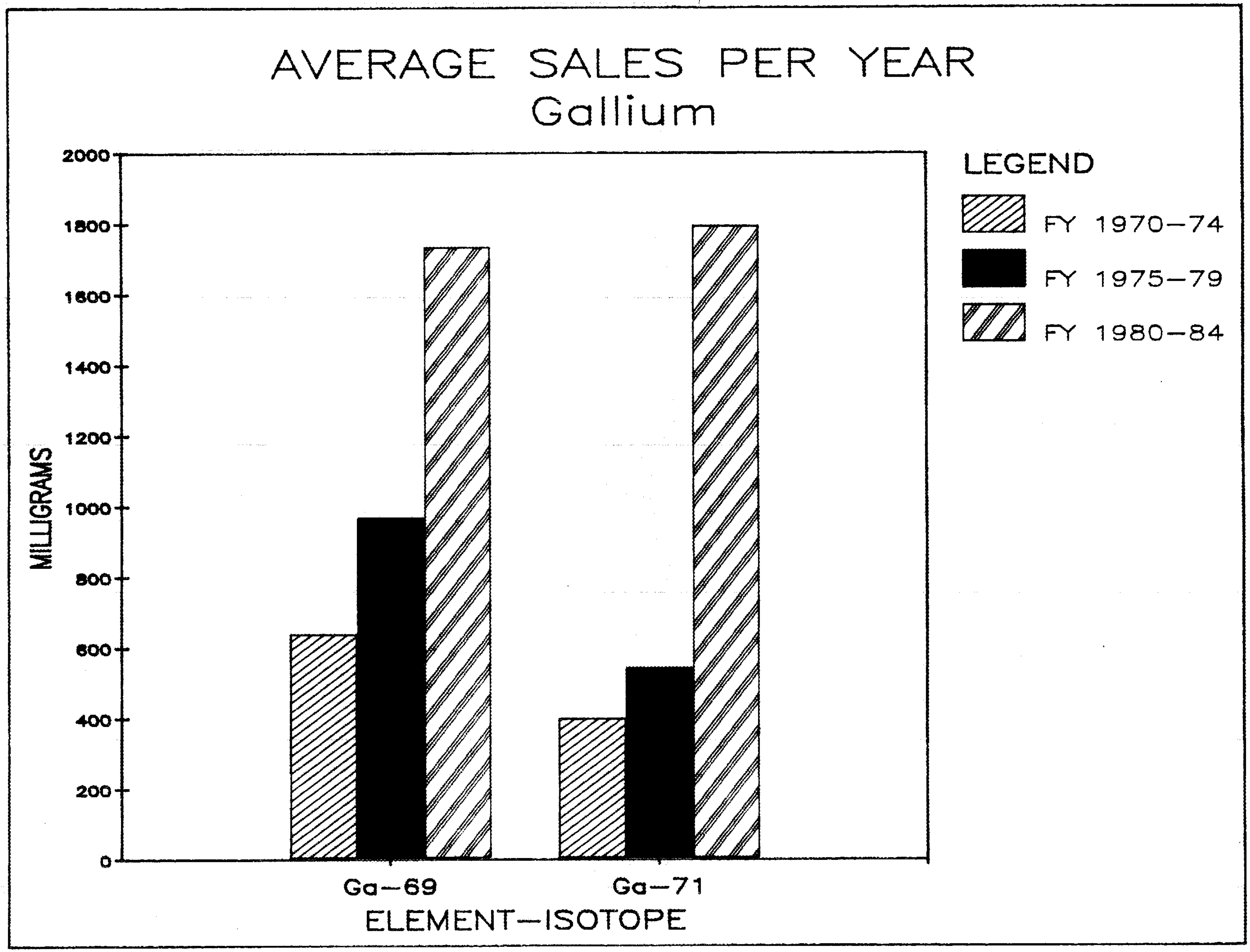
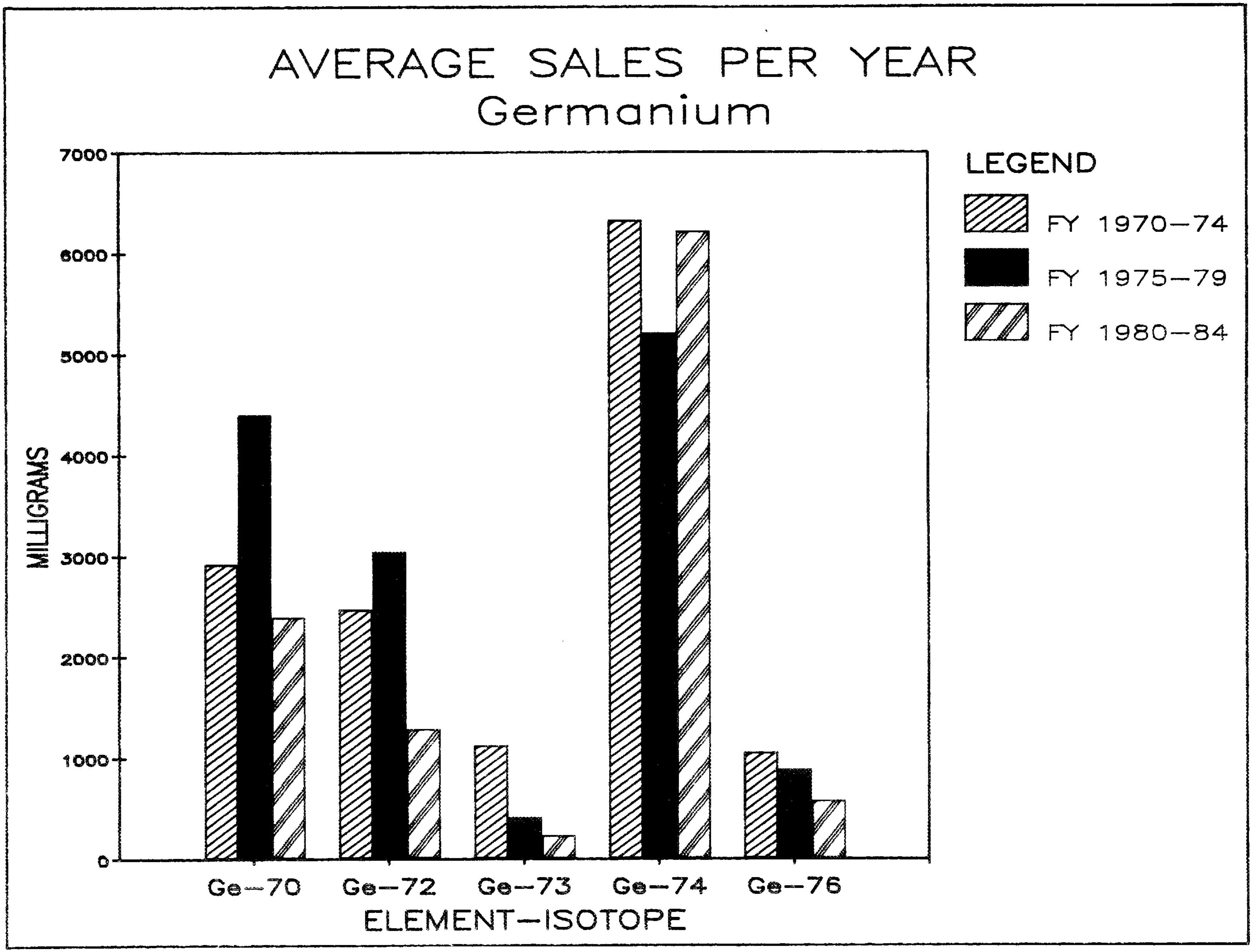
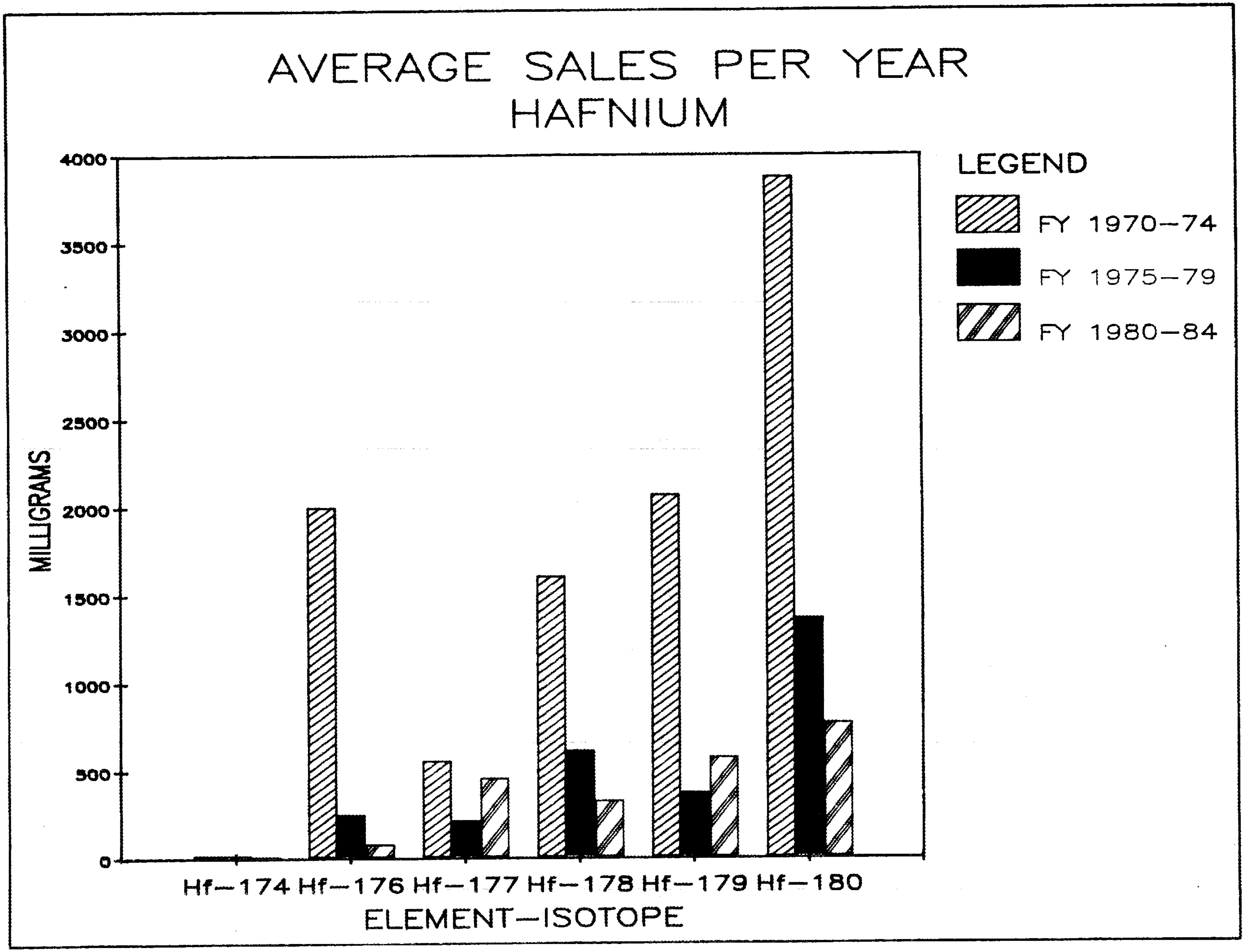
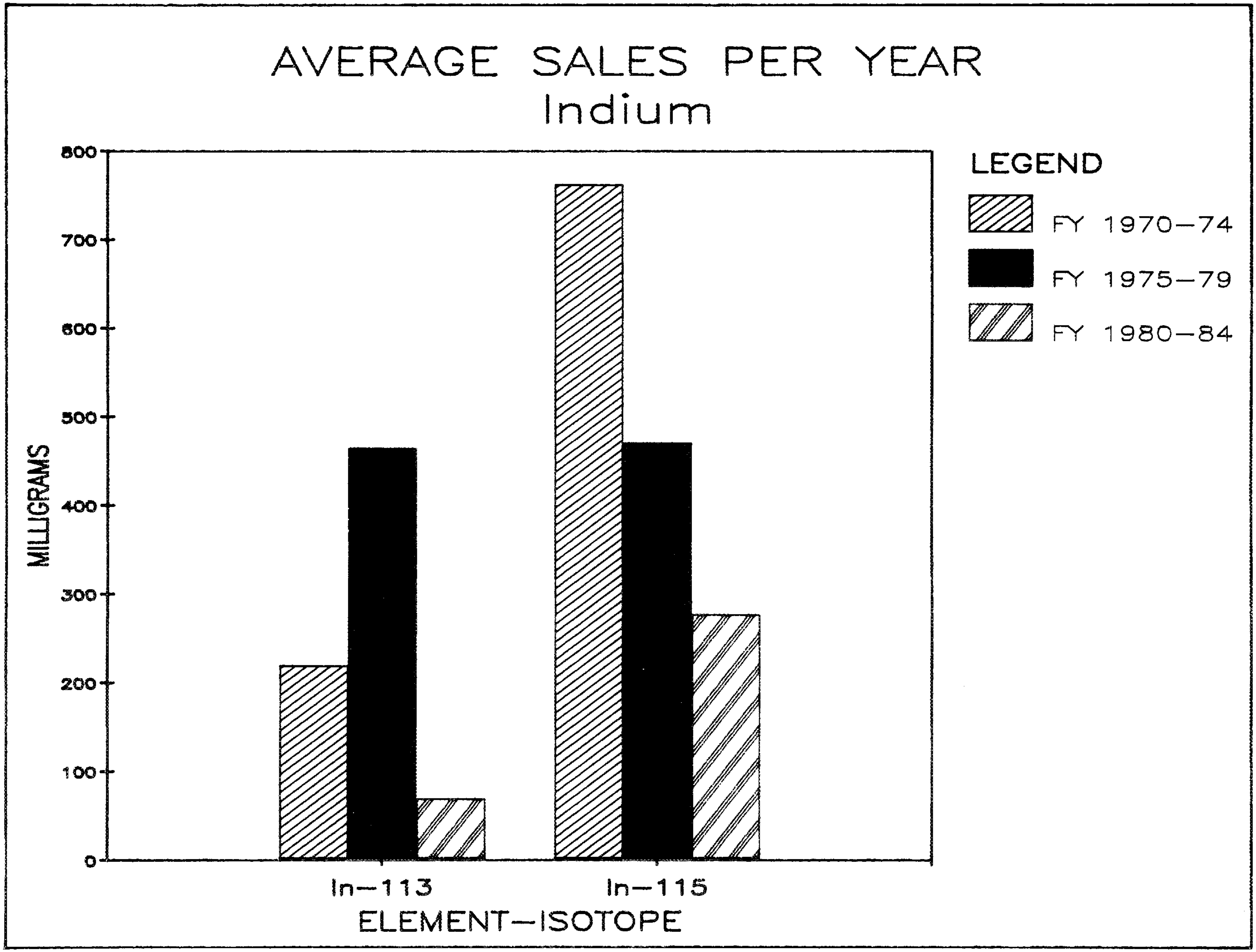
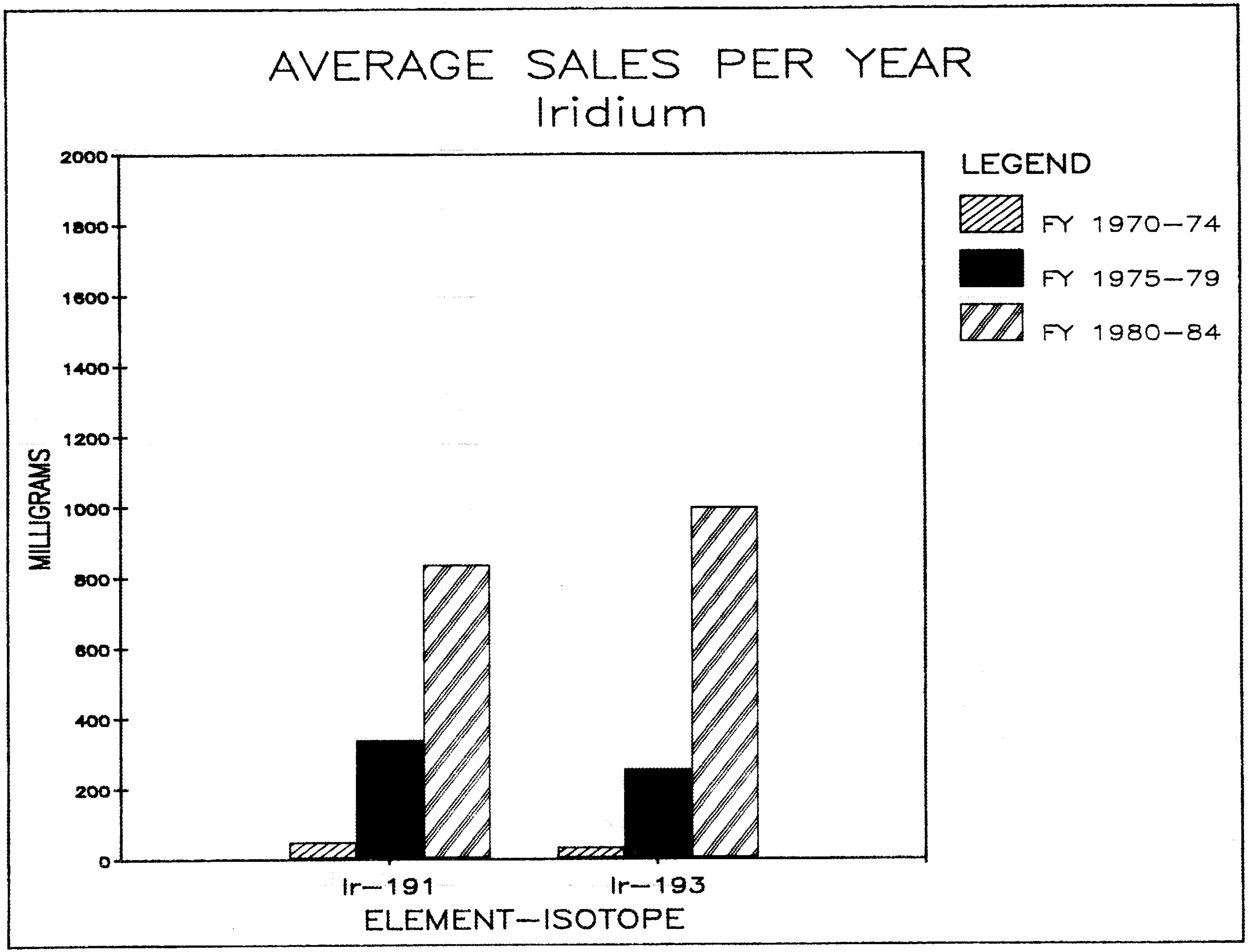
12000
10000
8000
6000
4000
2000
0
Gd-152
Gd-154
Gd-155
Gd-156
Gd-157
Gd-158
Gd-160
ELEMENT-ISOTOPE

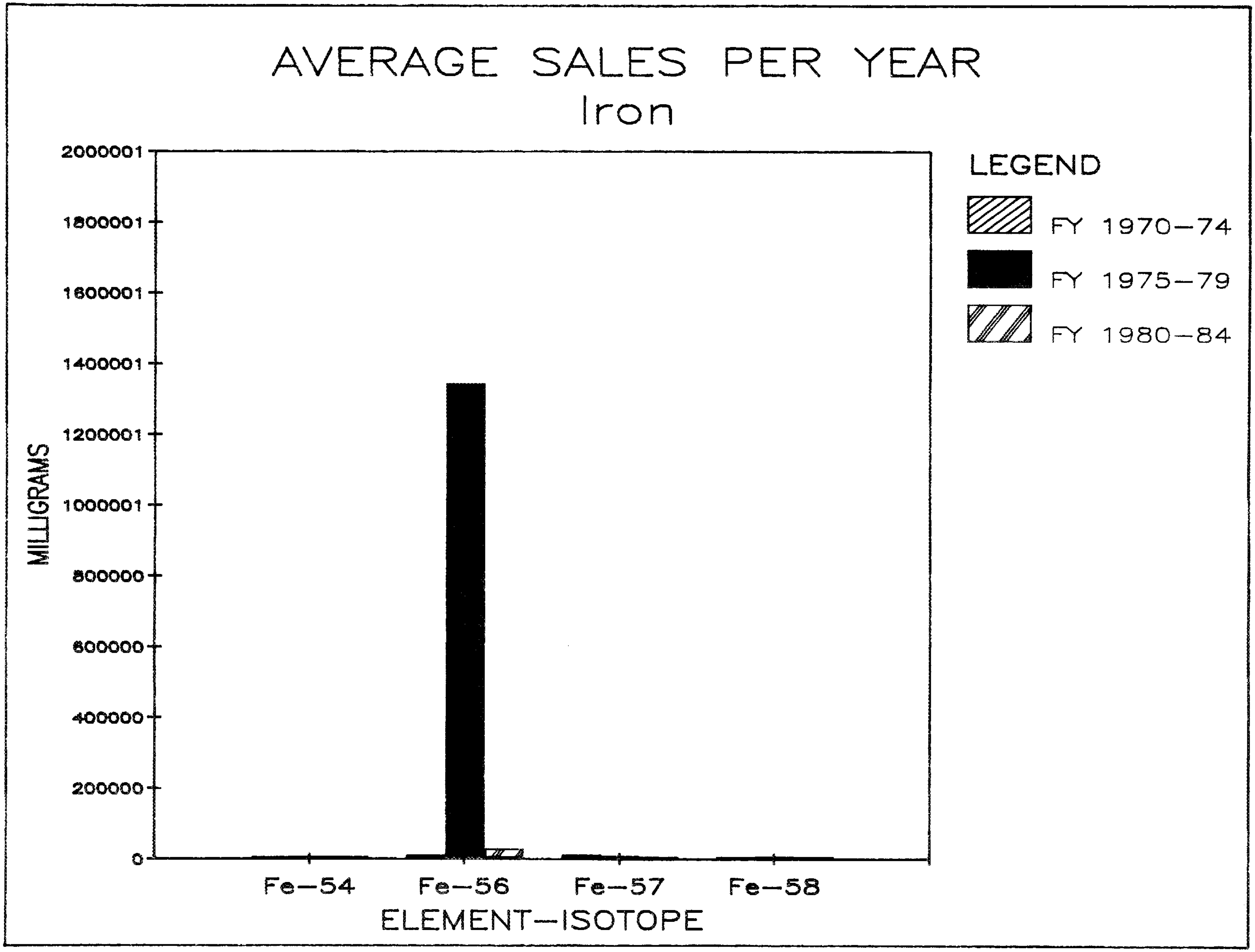

AVERAGE SALES PER YEAR
Gallium
MILLIGRAMS
2000
1800
1600
1400
1200
1000
800
600
400
200
0
Ga-69
Ga-71
ELEMENT-ISOTOPE
LEGEND
FY 1970-74
FY 1975-79
FY 1980-84

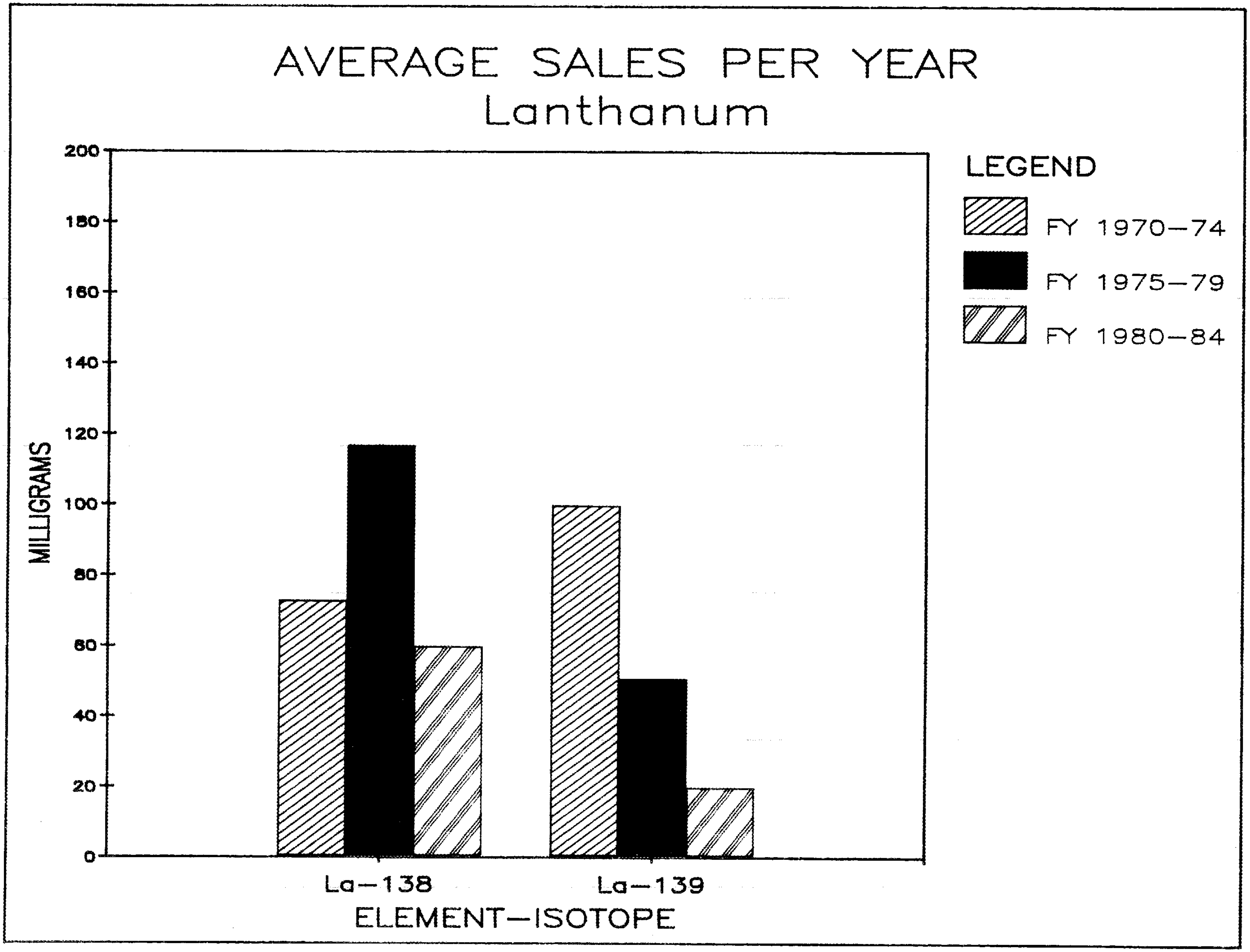

AVERAGE SALES PER YEAR
Germanium
MILLIGRAMS
7000
6000
5000
4000
3000
2000
1000
0
Ge-70
Ge-72
Ge-73
Ge-74
Ge-76
ELEMENT-ISOTOPE
LEGEND
FY 1970-74
FY 1975-79
FY 1980-84

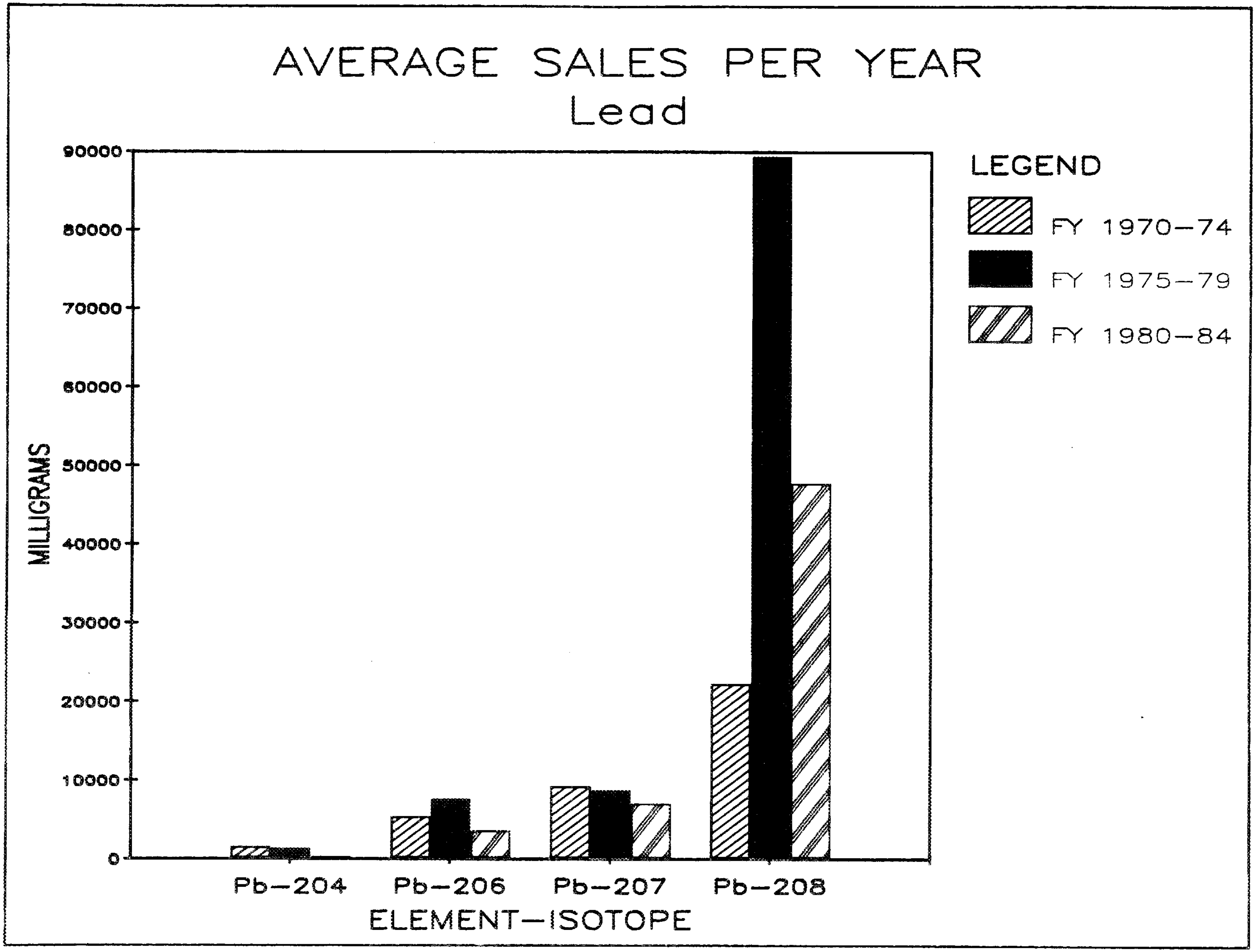

AVERAGE SALES PER YEAR
HAFNIUM
LEGEND
FY 1970-74
FY 1975-79
FY 1980-84
MILLIGRAMS
4000
3500
3000
2500
2000
1500
1000
500
0
Hf-174
Hf-176
Hf-177
Hf-178
Hf-179
Hf-180
ELEMENT-ISOTOPE

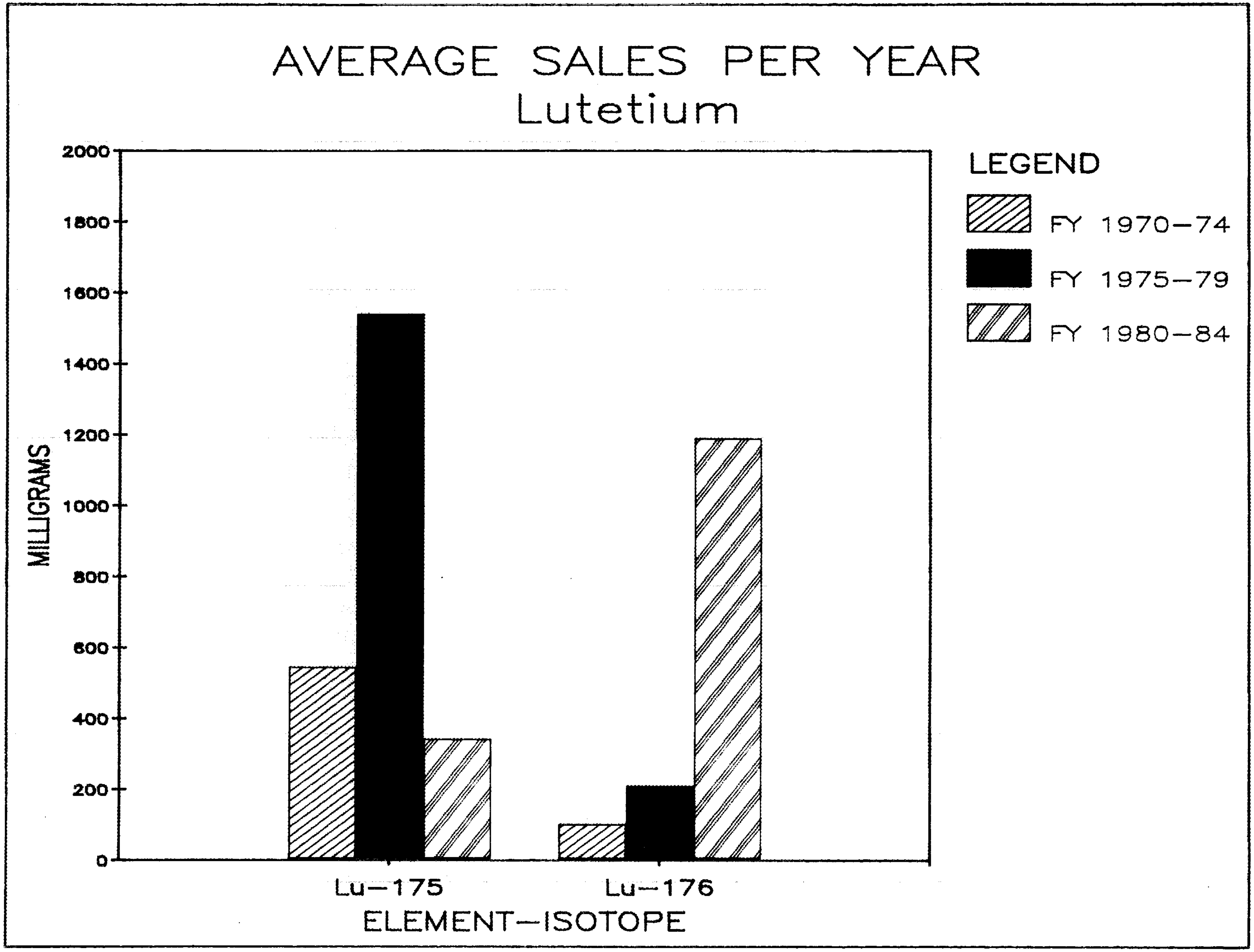

AVERAGE SALES PER YEAR
Indium
LEGEND
FY 1970–74
FY 1975–79
FY 1980–84
MILLIGRAMS
800
700
600
500
400
300
200
100
0
In–113
In–115
ELEMENT–ISOTOPE

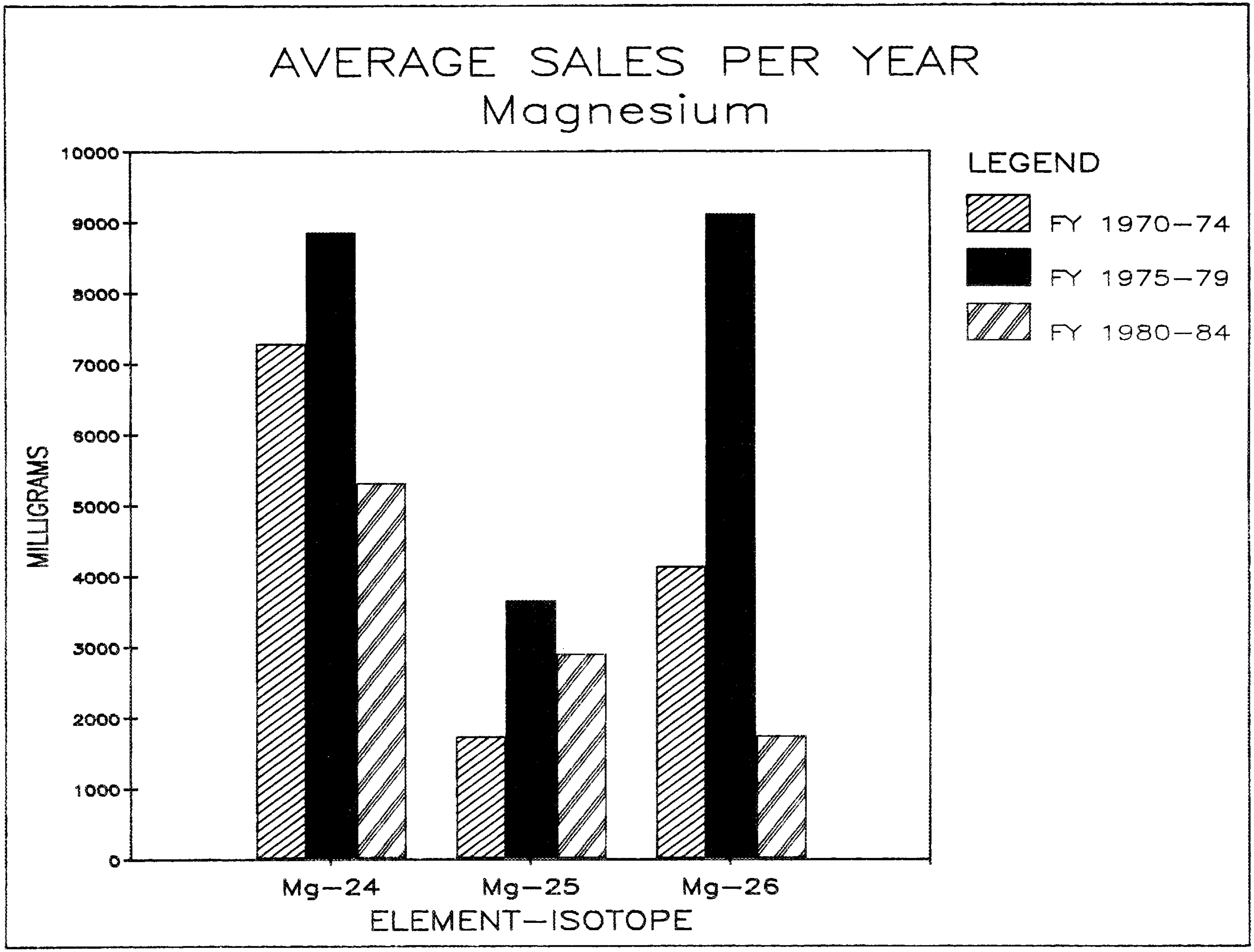

AVERAGE SALES PER YEAR
Iridium
2000
1800
1600
1400
1200
1000
800
600
400
200
0
MILLIGRAMS
Ir—191
Ir—193
ELEMENT—ISOTOPE
LEGEND
FY 1970—74
FY 1975—79
FY 1980—84

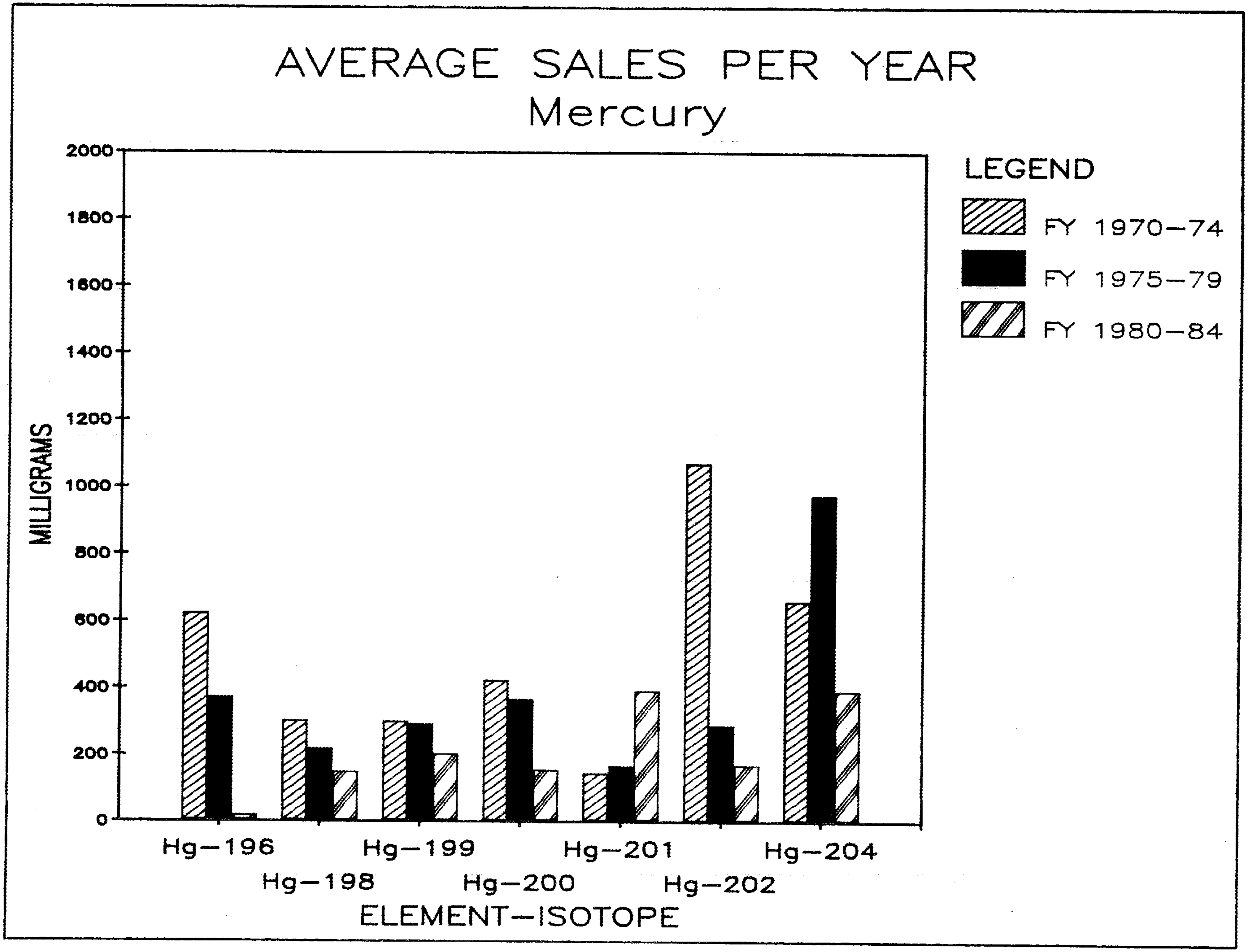

AVERAGE SALES PER YEAR
Iron
MILLIGRAMS
2000001
1800001
1600001
1400001
1200001
1000001
800000
600000
400000
200000
0
Fe—54
Fe—56
Fe—57
Fe—58
ELEMENT—ISOTOPE
LEGEND
FY 1970—74
FY 1975—79
FY 1980—84

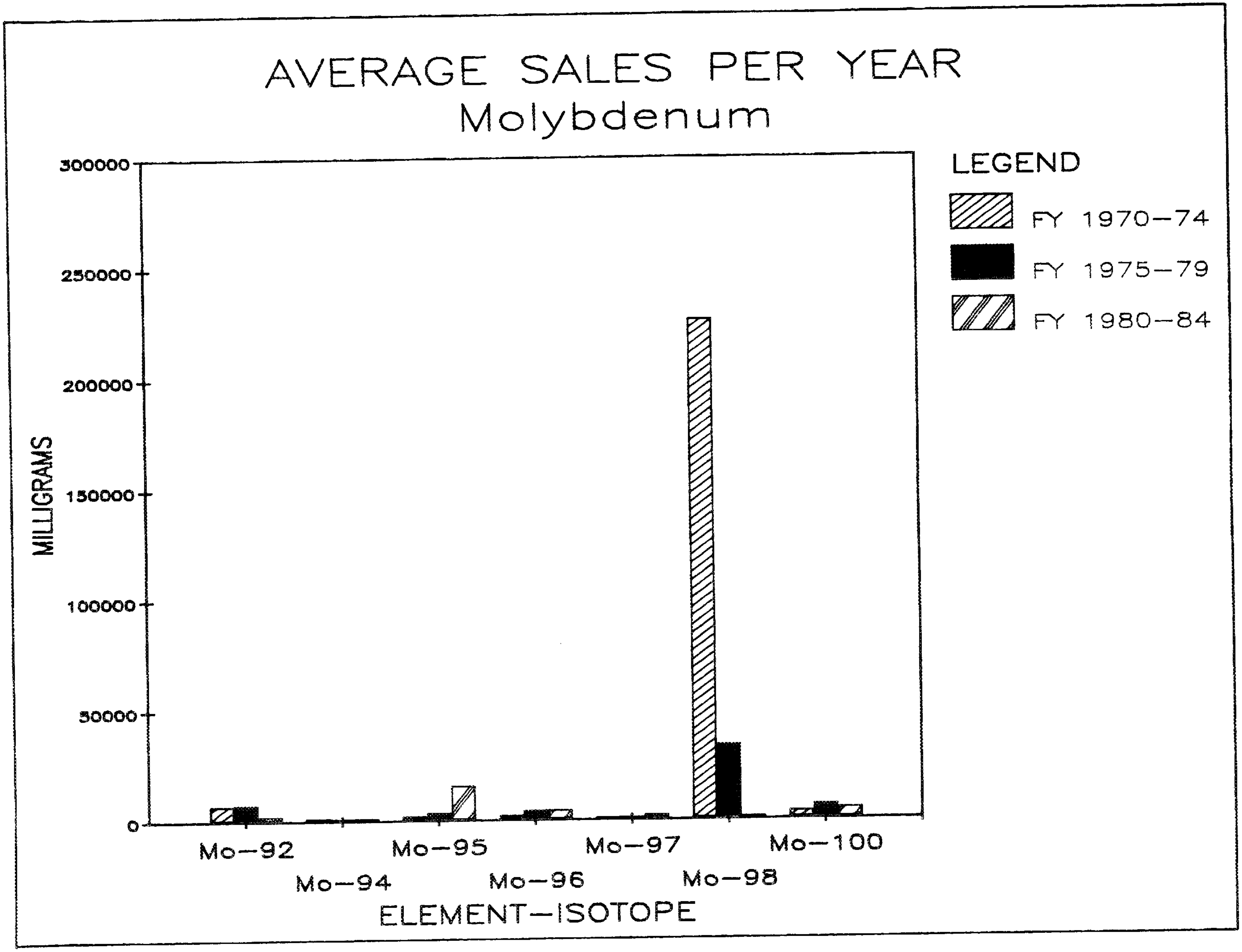

AVERAGE SALES PER YEAR
Lanthanum
MILLIGRAMS
200
180
160
140
120
100
80
60
40
20
0
La—138
La—139
ELEMENT—ISOTOPE
LEGEND
FY 1970—74
FY 1975—79
FY 1980—84

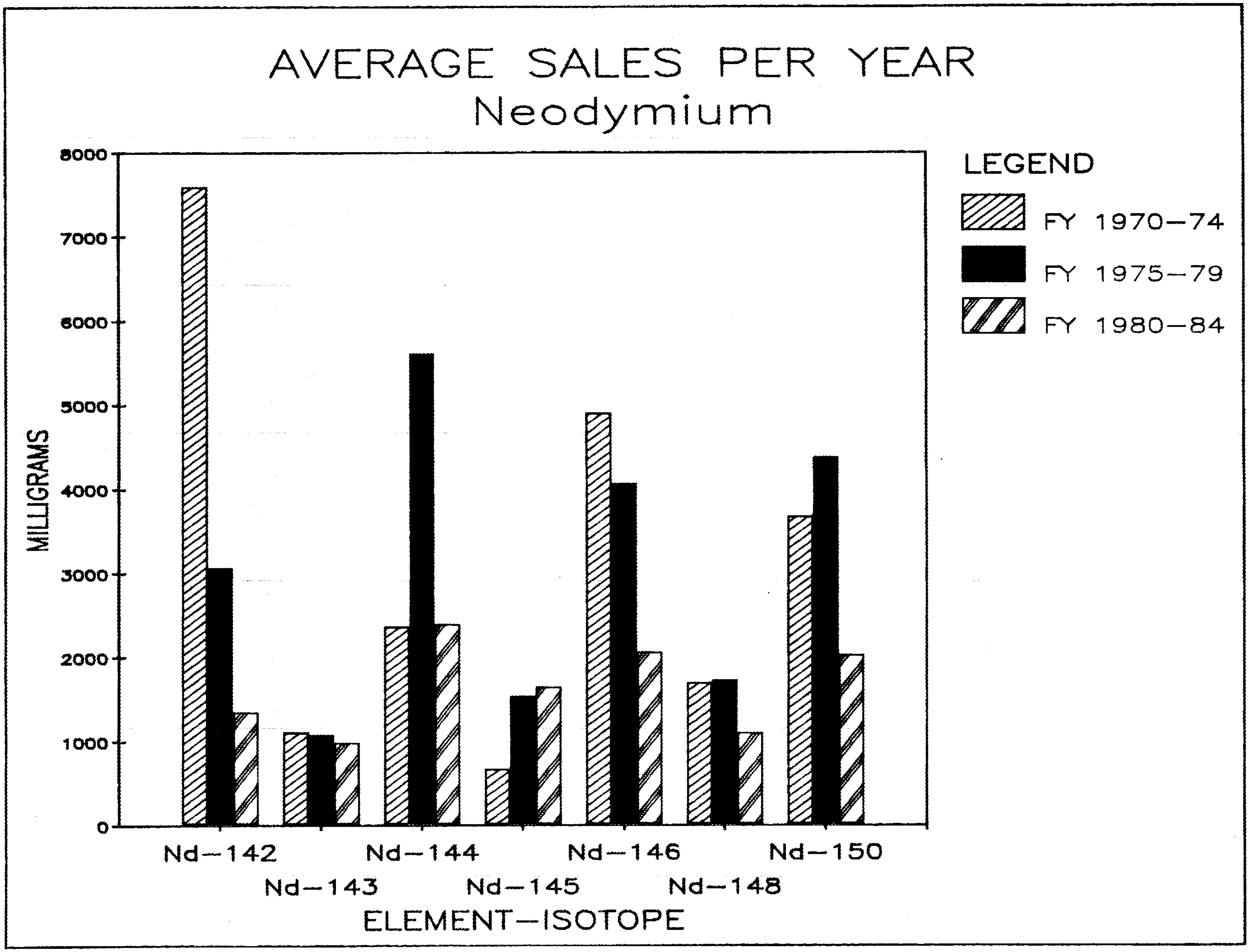

AVERAGE SALES PER YEAR
Lead
LEGEND
FY 1970-74
FY 1975-79
FY 1980-84
MILLIGRAMS
90000
80000
70000
60000
50000
40000
30000
20000
10000
0
Pb-204
Pb-206
Pb-207
Pb-208
ELEMENT-ISOTOPE

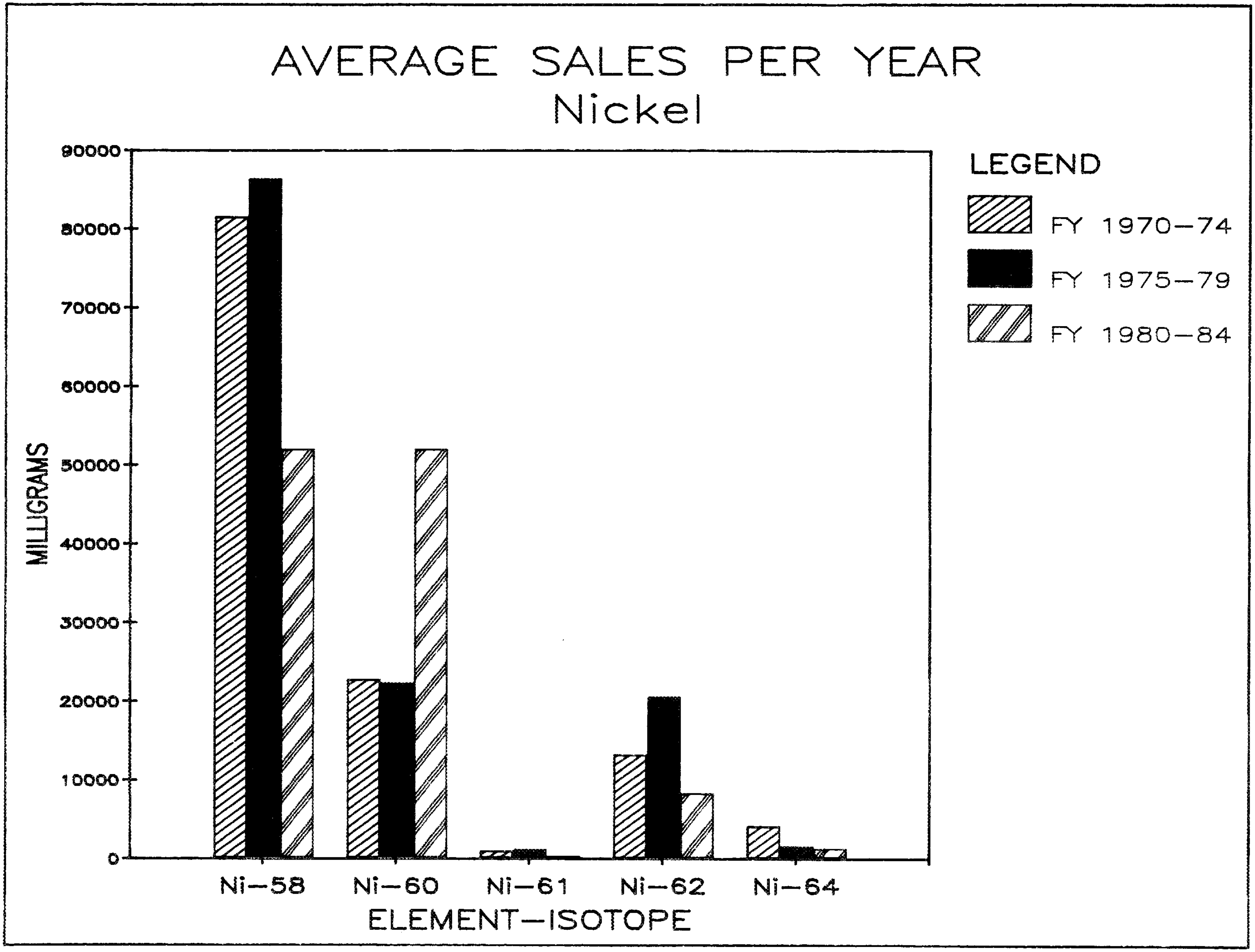

AVERAGE SALES PER YEAR
Lutetium
MILLIGRAMS
2000
1800
1600
1400
1200
1000
800
600
400
200
0
Lu-175
Lu-176
ELEMENT-ISOTOPE
LEGEND
FY 1970-74
FY 1975-79
FY 1980-84

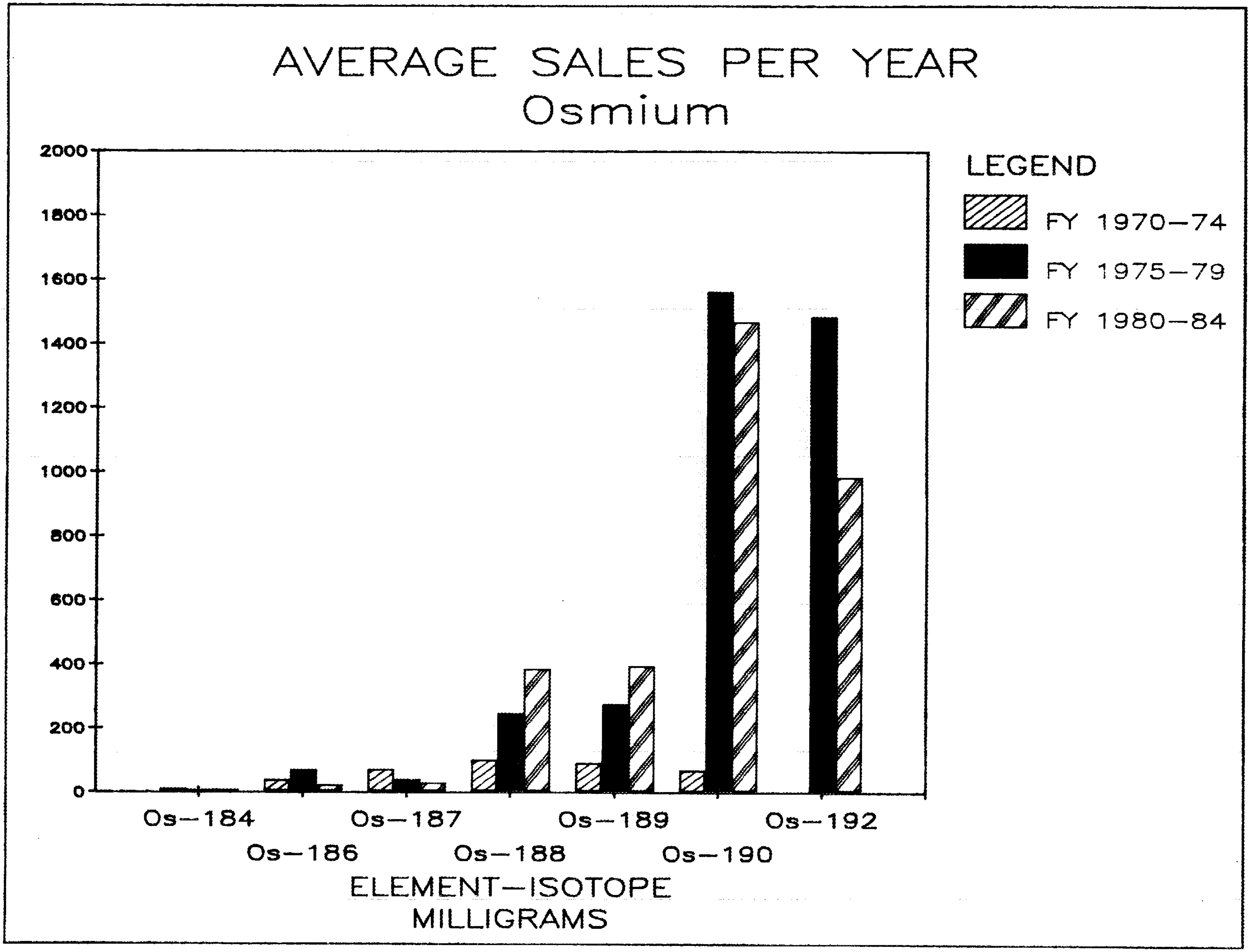

AVERAGE SALES PER YEAR
Magnesium
LEGEND
FY 1970-74
FY 1975-79
FY 1980-84
MILLIGRAMS
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
Mg-24
Mg-25
Mg-26
ELEMENT-ISOTOPE

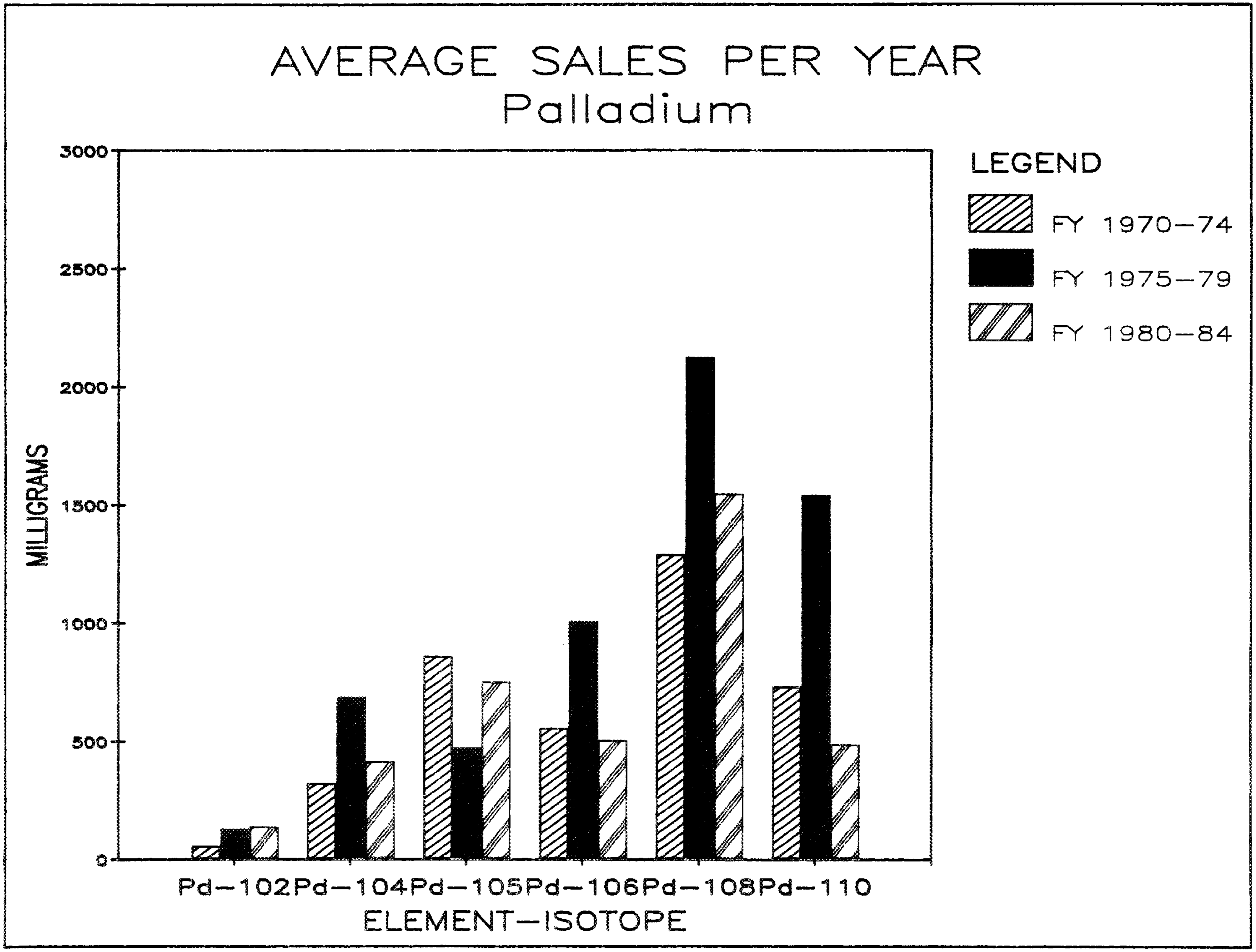

AVERAGE SALES PER YEAR
Mercury
MILLIGRAMS
0
200
400
600
800
1000
1200
1400
1600
1800
2000
LEGEND
FY 1970-74
FY 1975-79
FY 1980-84
Hg-196
Hg-198
Hg-199
Hg-200
Hg-201
Hg-202
Hg-204
ELEMENT-ISOTOPE

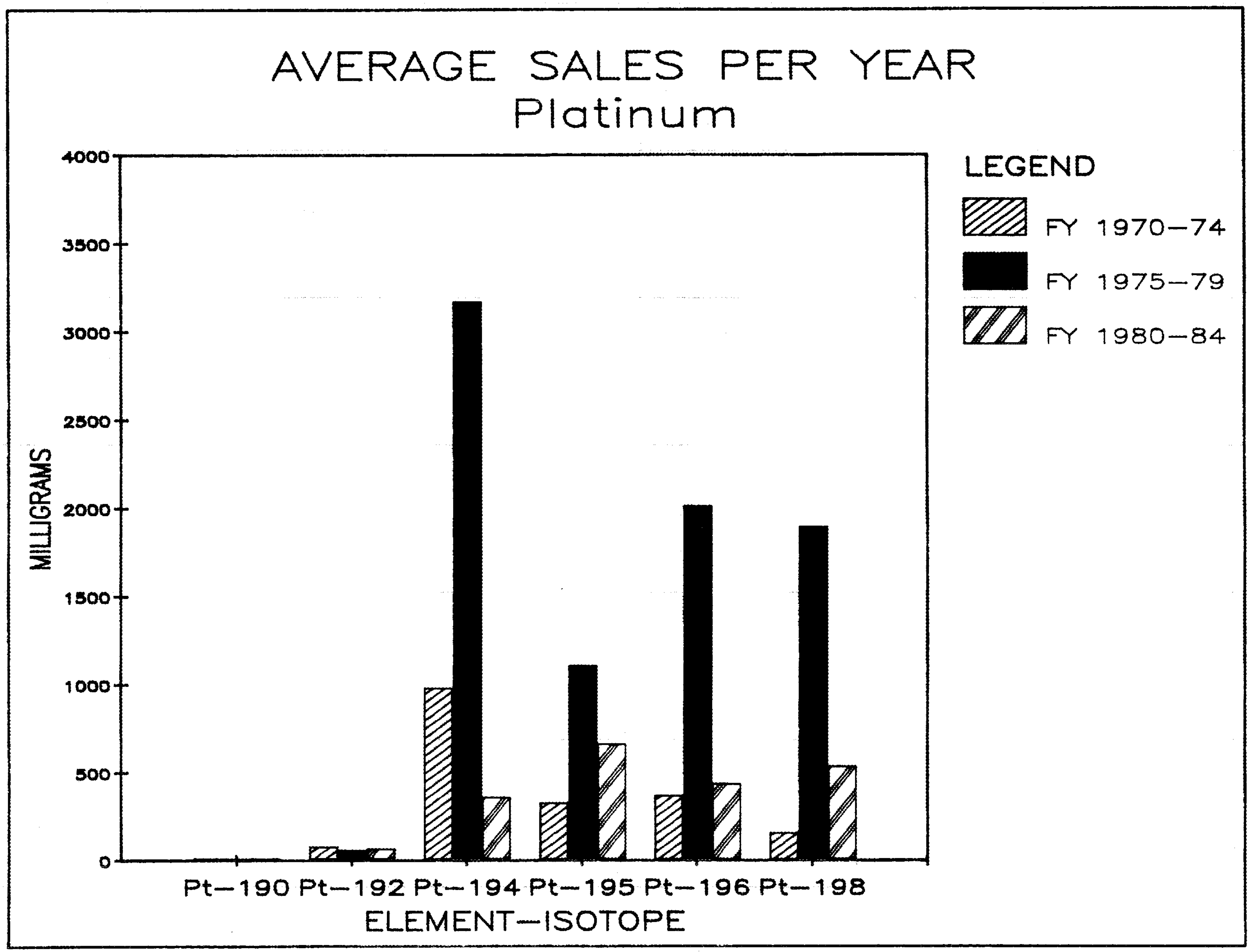

AVERAGE SALES PER YEAR
Molybdenum
LEGEND
FY 1970–74
FY 1975–79
FY 1980–84
MILLIGRAMS
300000
250000
200000
150000
100000
50000
0
Mo–92
Mo–94
Mo–95
Mo–96
Mo–97
Mo–98
Mo–100
ELEMENT–ISOTOPE

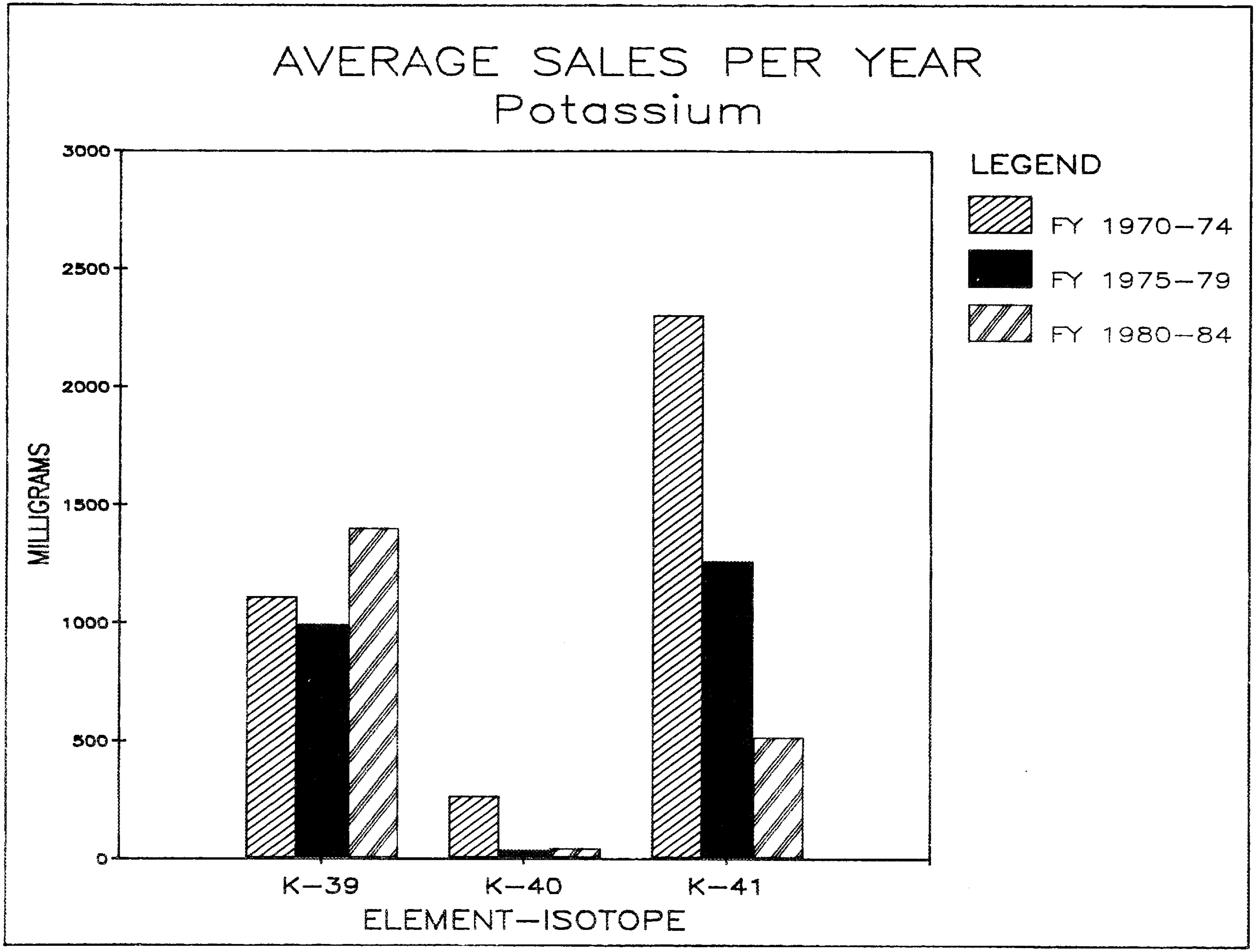

AVERAGE SALES PER YEAR
Neodymium
MILLIGRAMS
8000
7000
6000
5000
4000
3000
2000
1000
0
Nd-142
Nd-143
Nd-144
Nd-145
Nd-146
Nd-148
Nd-150
ELEMENT-ISOTOPE
LEGEND
FY 1970-74
FY 1975-79
FY 1980-84

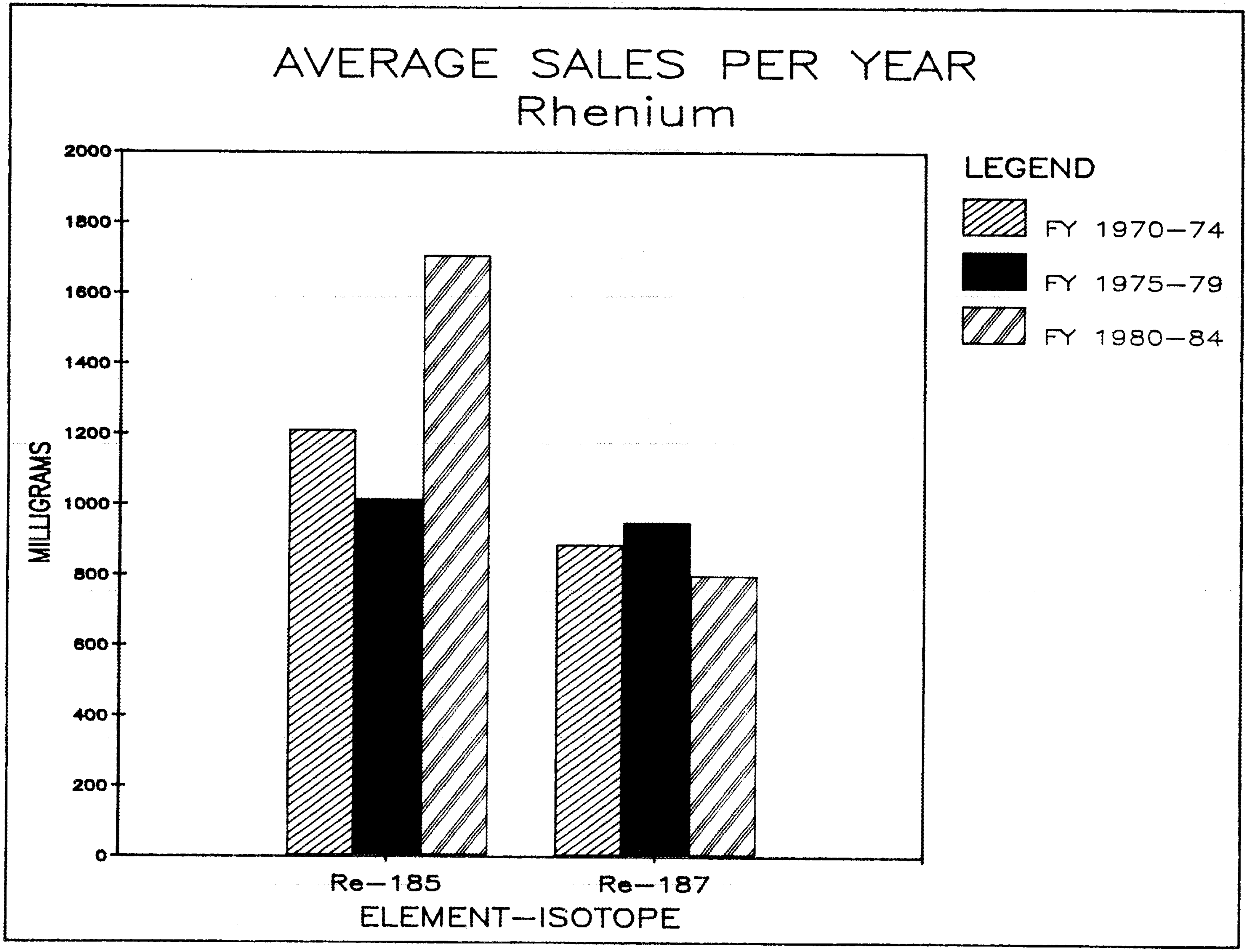

AVERAGE SALES PER YEAR
Nickel
MILLIGRAMS
90000
80000
70000
60000
50000
40000
30000
20000
10000
0
Ni-58
Ni-60
Ni-61
Ni-62
Ni-64
ELEMENT-ISOTOPE
LEGEND
FY 1970-74
FY 1975-79
FY 1980-84

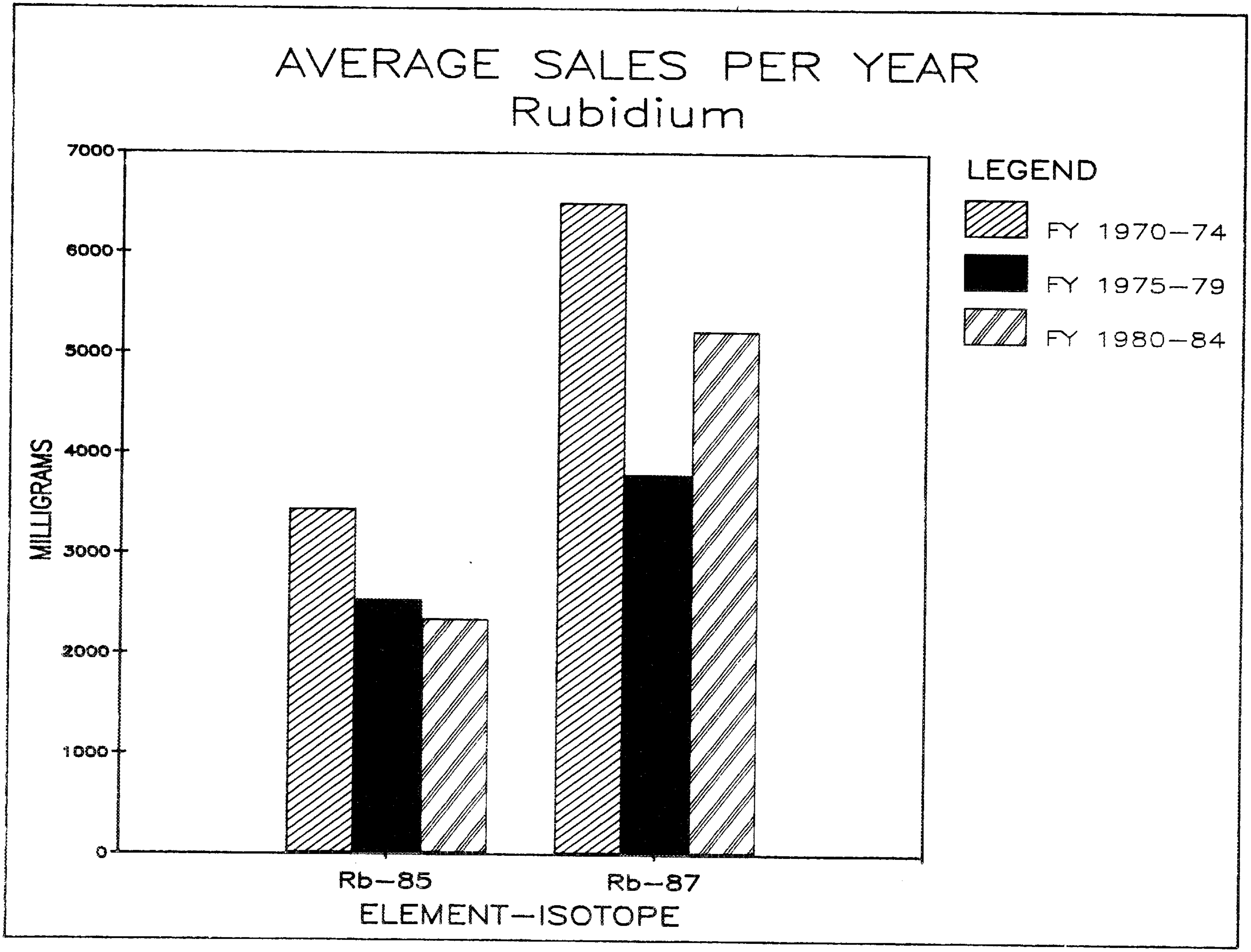

AVERAGE SALES PER YEAR
Osmium
2000
1800
1600
1400
1200
1000
800
600
400
200
0
LEGEND
FY 1970–74
FY 1975–79
FY 1980–84
Os–184
Os–186
Os–187
Os–188
Os–189
Os–190
Os–192
ELEMENT–ISOTOPE
MILLIGRAMS

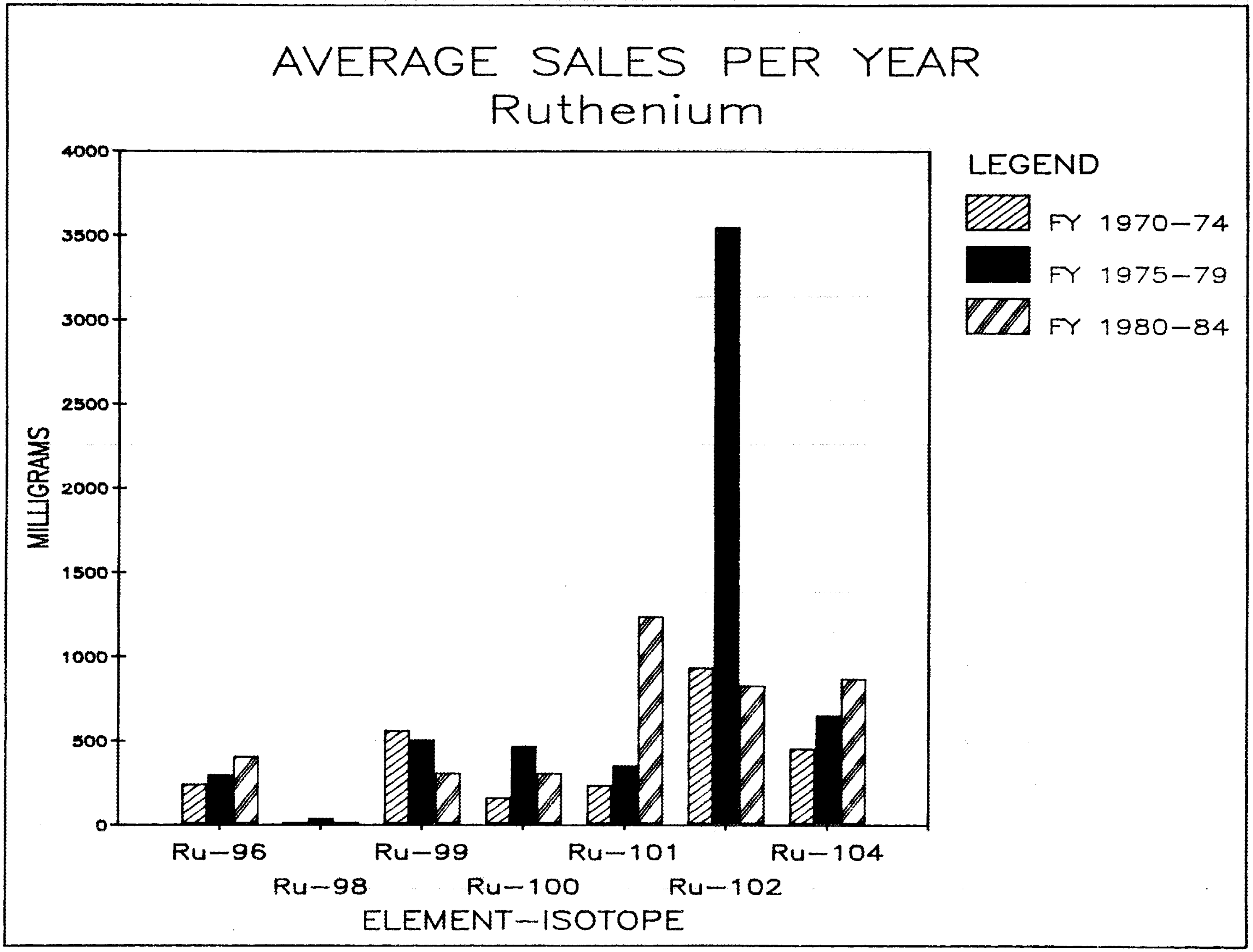

AVERAGE SALES PER YEAR
Palladium
LEGEND
FY 1970-74
FY 1975-79
FY 1980-84
MILLIGRAMS
3000
2500
2000
1500
1000
500
0
Pd-102
Pd-104
Pd-105
Pd-106
Pd-108
Pd-110
ELEMENT-ISOTOPE

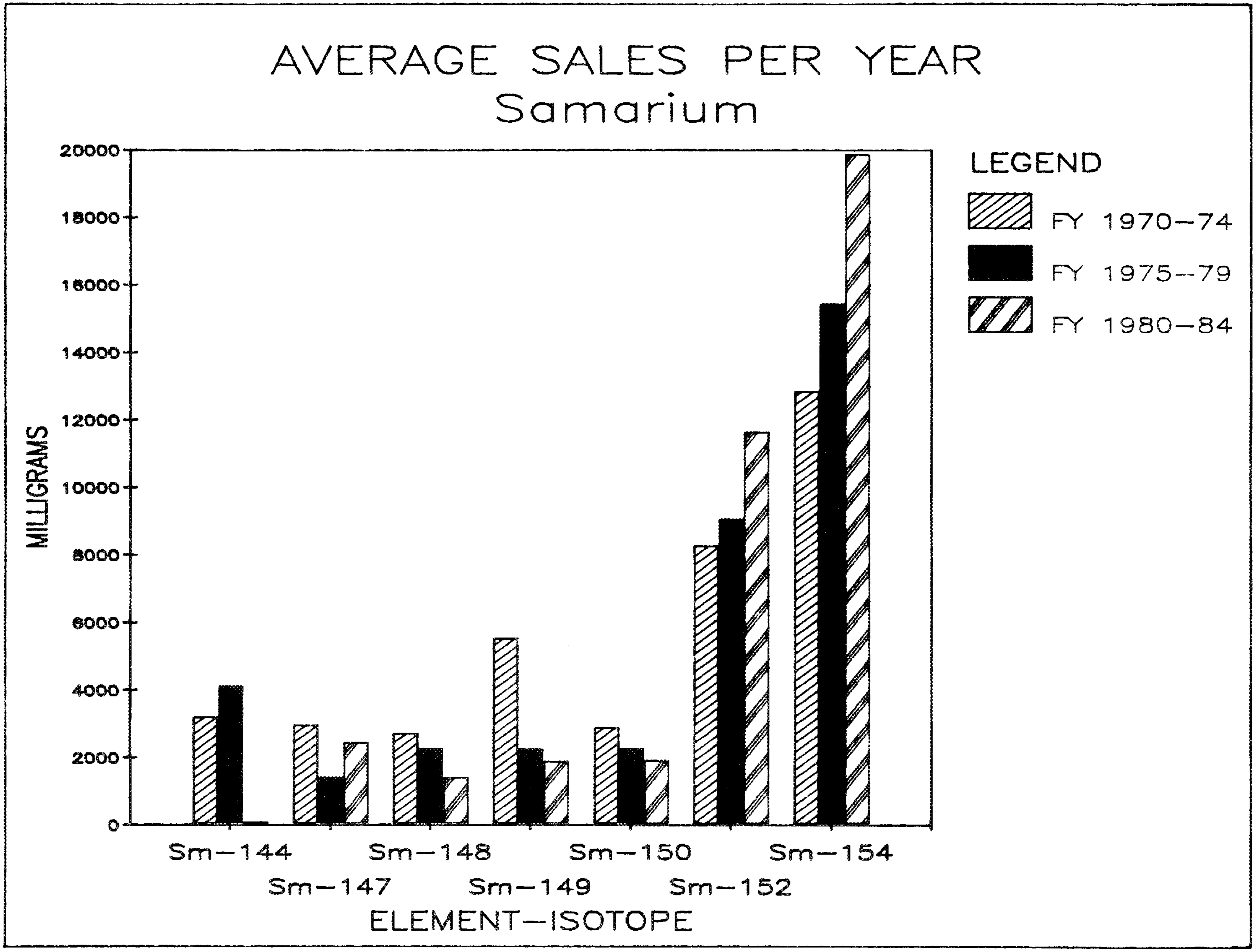

AVERAGE SALES PER YEAR
Platinum
LEGEND
FY 1970–74
FY 1975–79
FY 1980–84
MILLIGRAMS
4000
3500
3000
2500
2000
1500
1000
500
0
Pt–190 Pt–192 Pt–194 Pt–195 Pt–196 Pt–198
ELEMENT–ISOTOPE

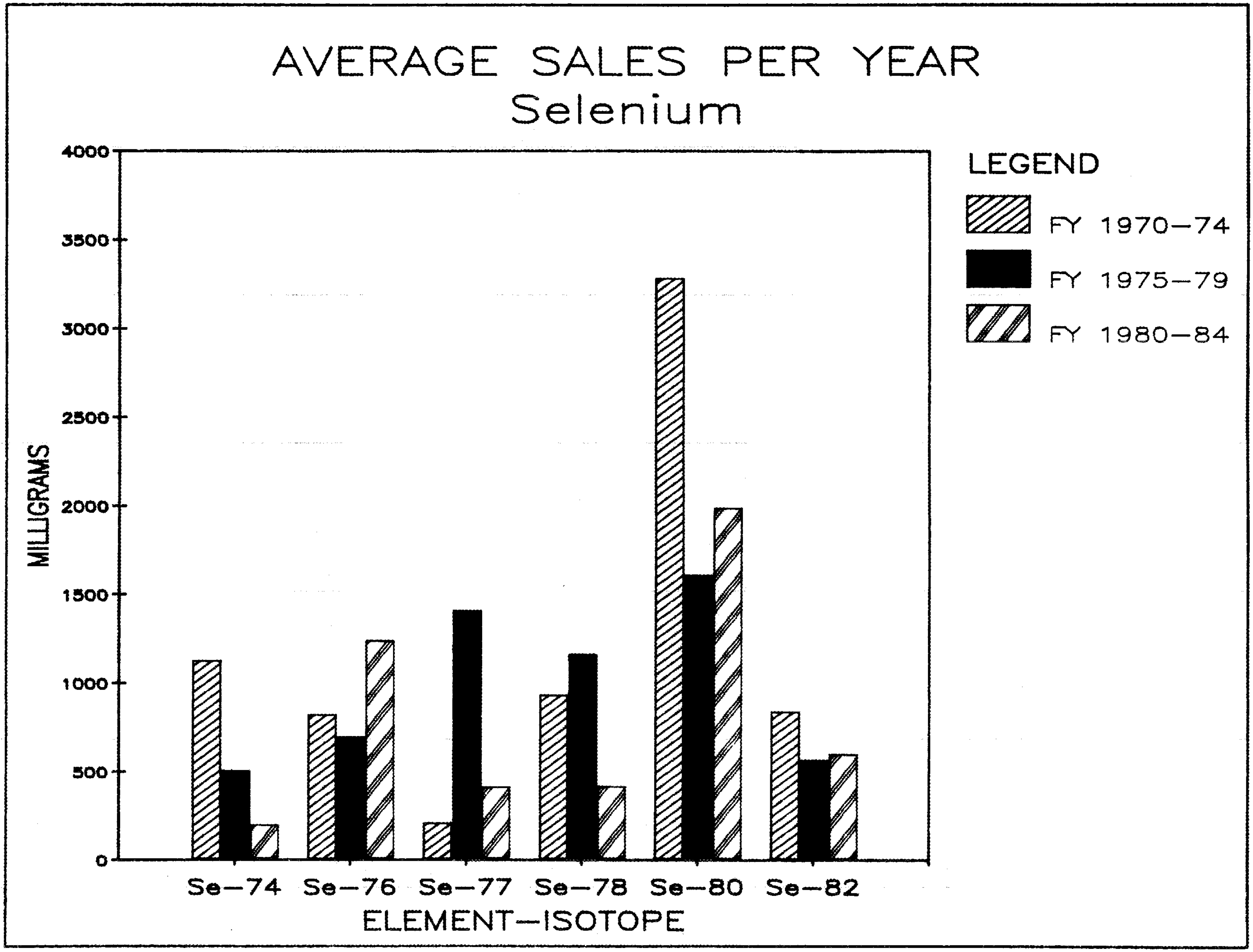

AVERAGE SALES PER YEAR
Potassium
LEGEND
FY 1970-74
FY 1975-79
FY 1980-84
MILLIGRAMS
3000
2500
2000
1500
1000
500
0
K-39
K-40
K-41
ELEMENT-ISOTOPE

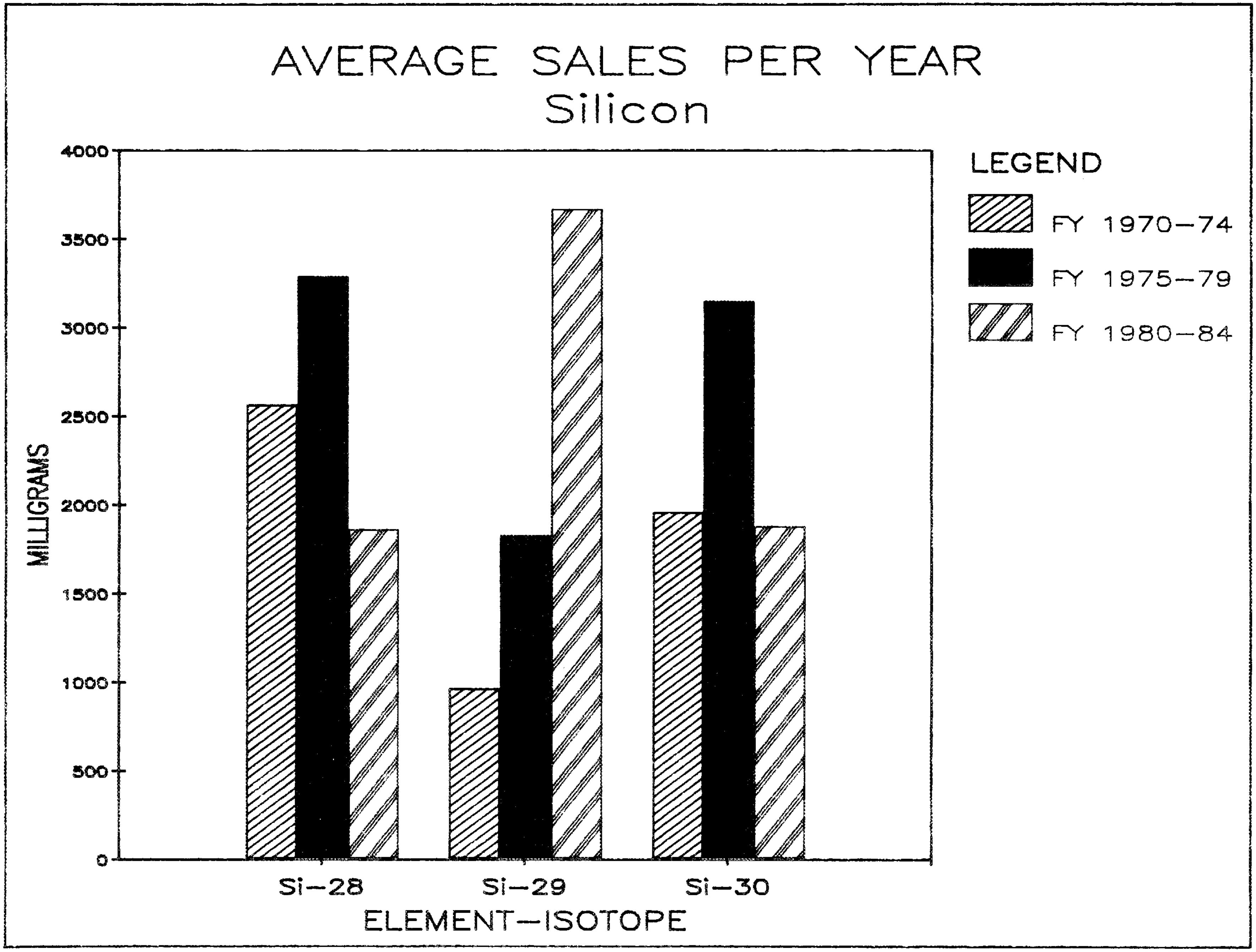

AVERAGE SALES PER YEAR
Rhenium
LEGEND
FY 1970–74
FY 1975–79
FY 1980–84
MILLIGRAMS
2000
1800
1600
1400
1200
1000
800
600
400
200
0
Re–185
Re–187
ELEMENT–ISOTOPE

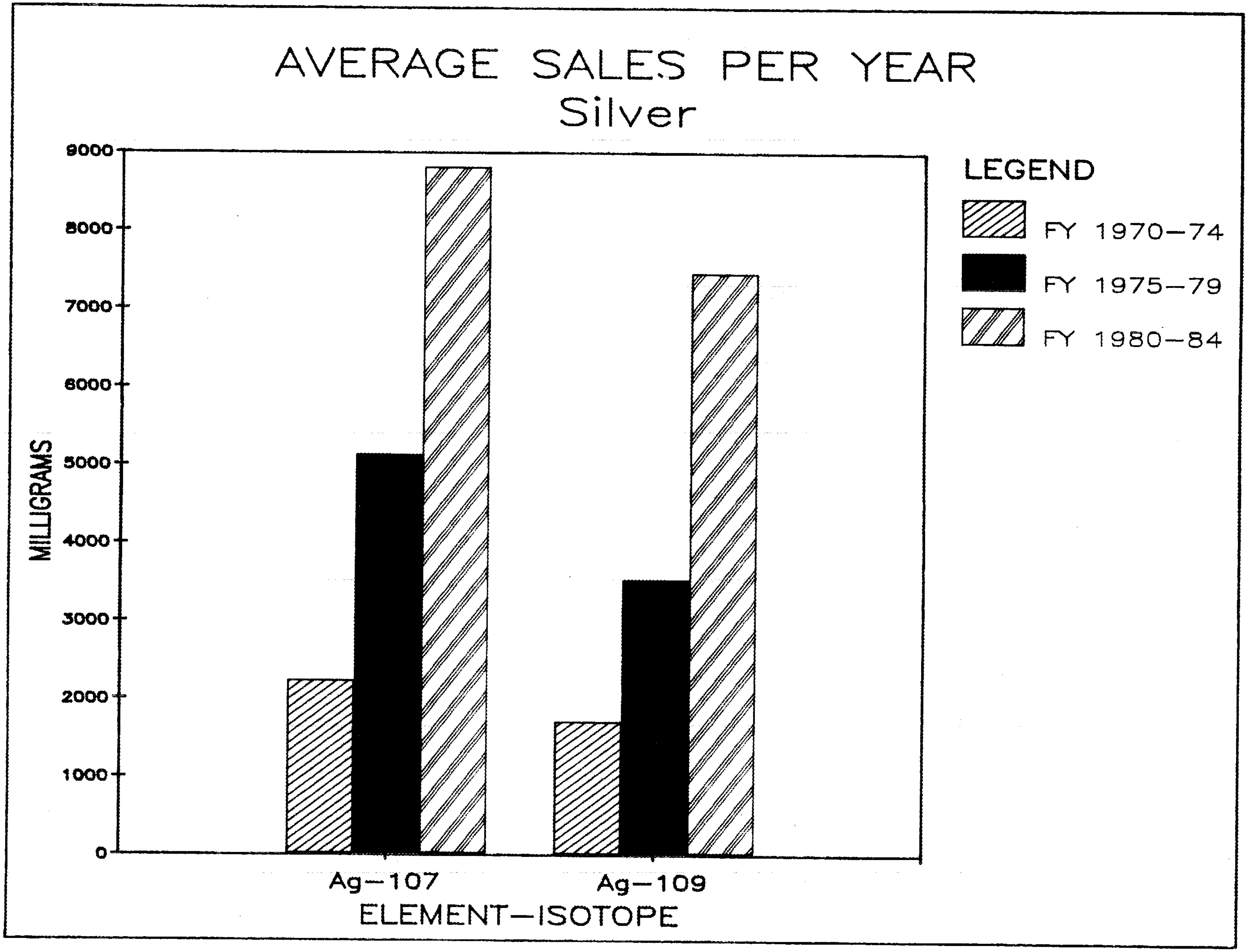

AVERAGE SALES PER YEAR
Rubidium
LEGEND
FY 1970-74
FY 1975-79
FY 1980-84
MILLIGRAMS
7000
6000
5000
4000
3000
2000
1000
0
Rb-85
Rb-87
ELEMENT-ISOTOPE

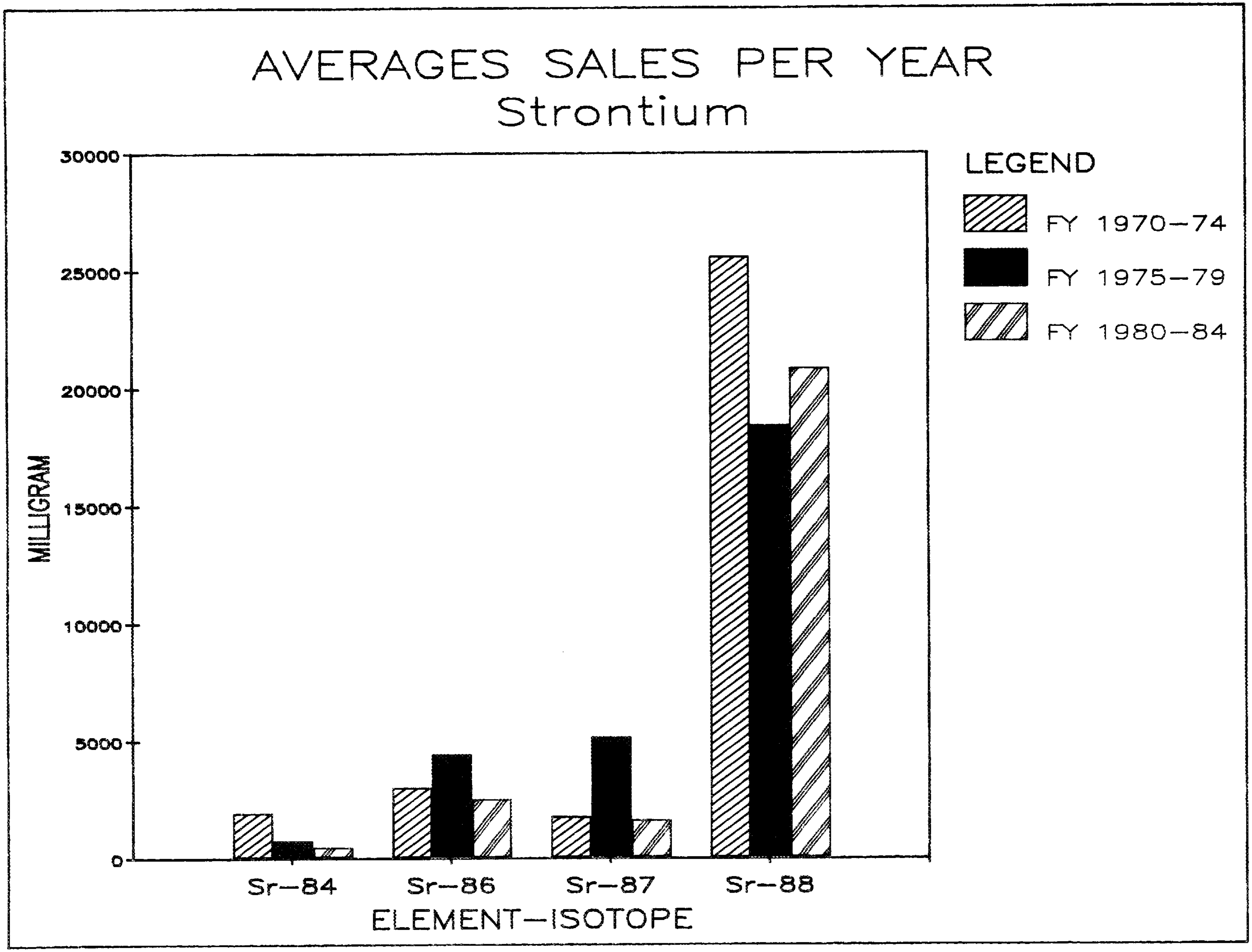

AVERAGE SALES PER YEAR
Ruthenium
LEGEND
FY 1970-74
FY 1975-79
FY 1980-84
MILLIGRAMS
4000
3500
3000
2500
2000
1500
1000
500
0
Ru-96
Ru-98
Ru-99
Ru-100
Ru-101
Ru-102
Ru-104
ELEMENT-ISOTOPE

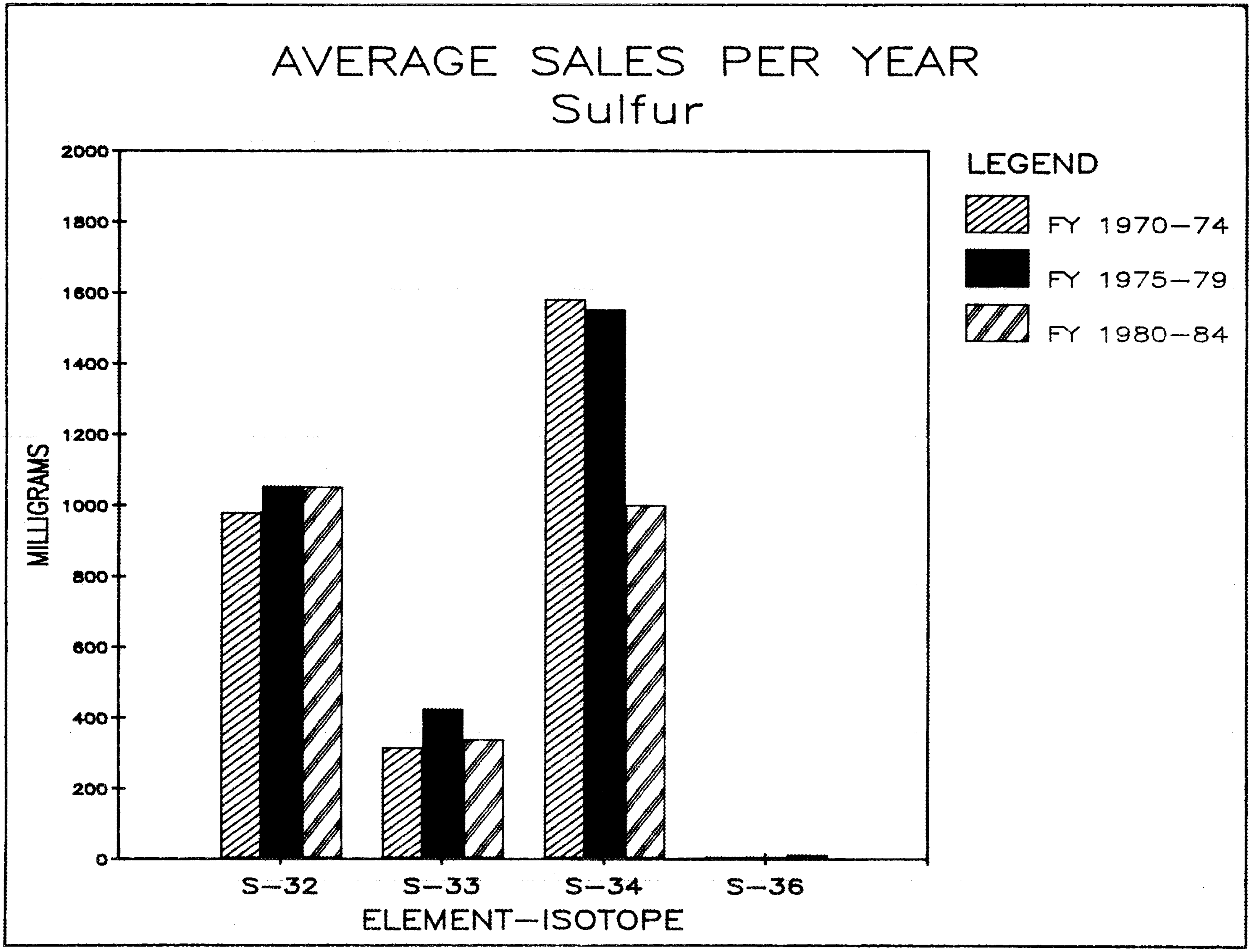

AVERAGE SALES PER YEAR
Samarium
MILLIGRAMS
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
Sm-144
Sm-147
Sm-148
Sm-149
Sm-150
Sm-152
Sm-154
ELEMENT-ISOTOPE
LEGEND
FY 1970-74
FY 1975--79
FY 1980-84


AVERAGE SALES PER YEAR
Selenium
LEGEND
FY 1970-74
FY 1975-79
FY 1980-84
MILLIGRAMS
4000
3500
3000
2500
2000
1500
1000
500
0
Se-74
Se-76
Se-77
Se-78
Se-80
Se-82
ELEMENT-ISOTOPE


AVERAGE SALES PER YEAR
Silicon
MILLIGRAMS
4000
3500
3000
2500
2000
1500
1000
500
0
Si-28
Si-29
Si-30
ELEMENT-ISOTOPE
LEGEND
FY 1970-74
FY 1975-79
FY 1980-84


AVERAGE SALES PER YEAR
Silver
MILLIGRAMS
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Ag-107
Ag-109
ELEMENT-ISOTOPE
LEGEND
FY 1970-74
FY 1975-79
FY 1980-84


AVERAGES SALES PER YEAR
Strontium
MILLIGRAM
30000
25000
20000
15000
10000
5000
0
Sr-84
Sr-86
Sr-87
Sr-88
ELEMENT-ISOTOPE
LEGEND
FY 1970-74
FY 1975-79
FY 1980-84


AVERAGE SALES PER YEAR
Sulfur
LEGEND
FY 1970-74
FY 1975-79
FY 1980-84
MILLIGRAMS
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200
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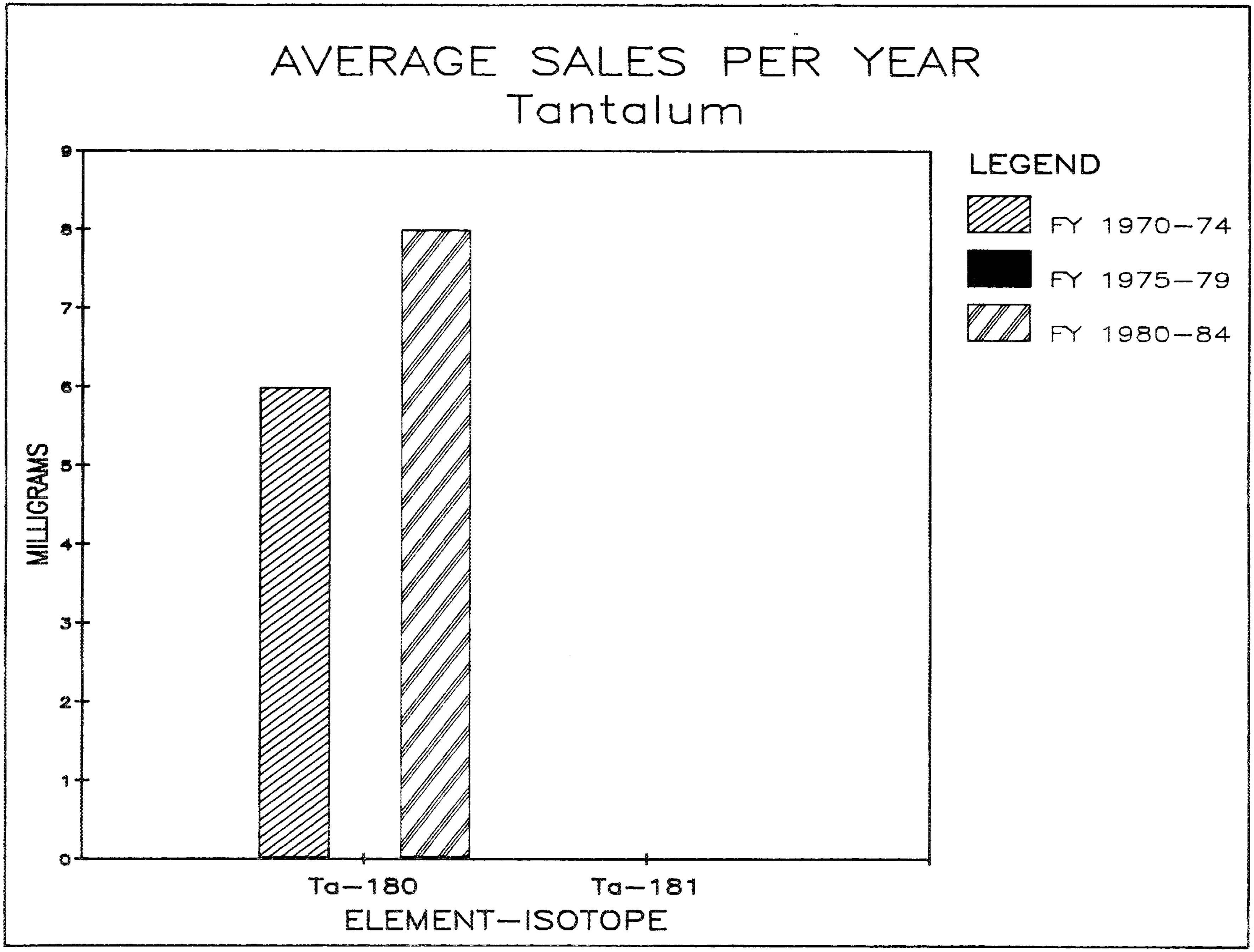
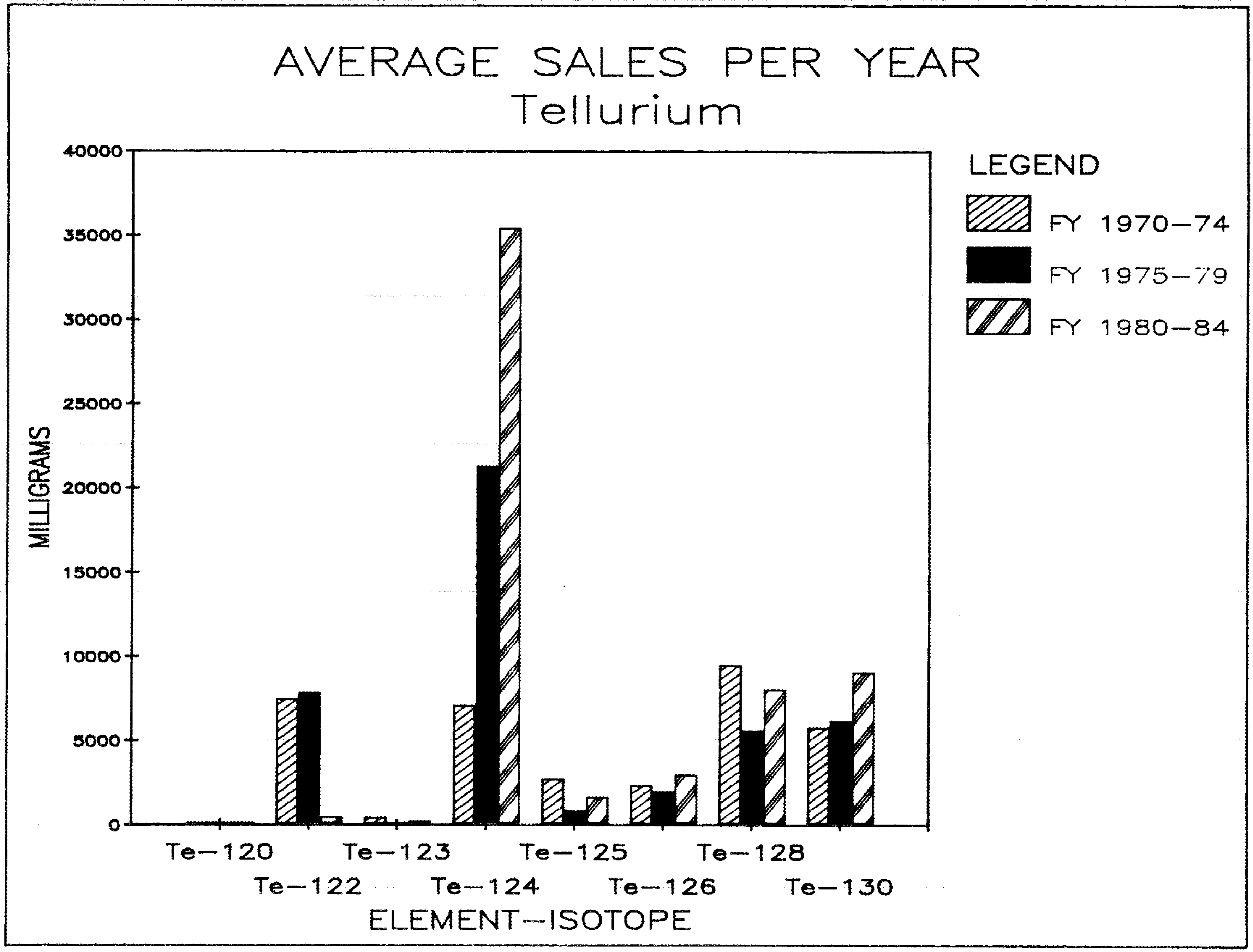
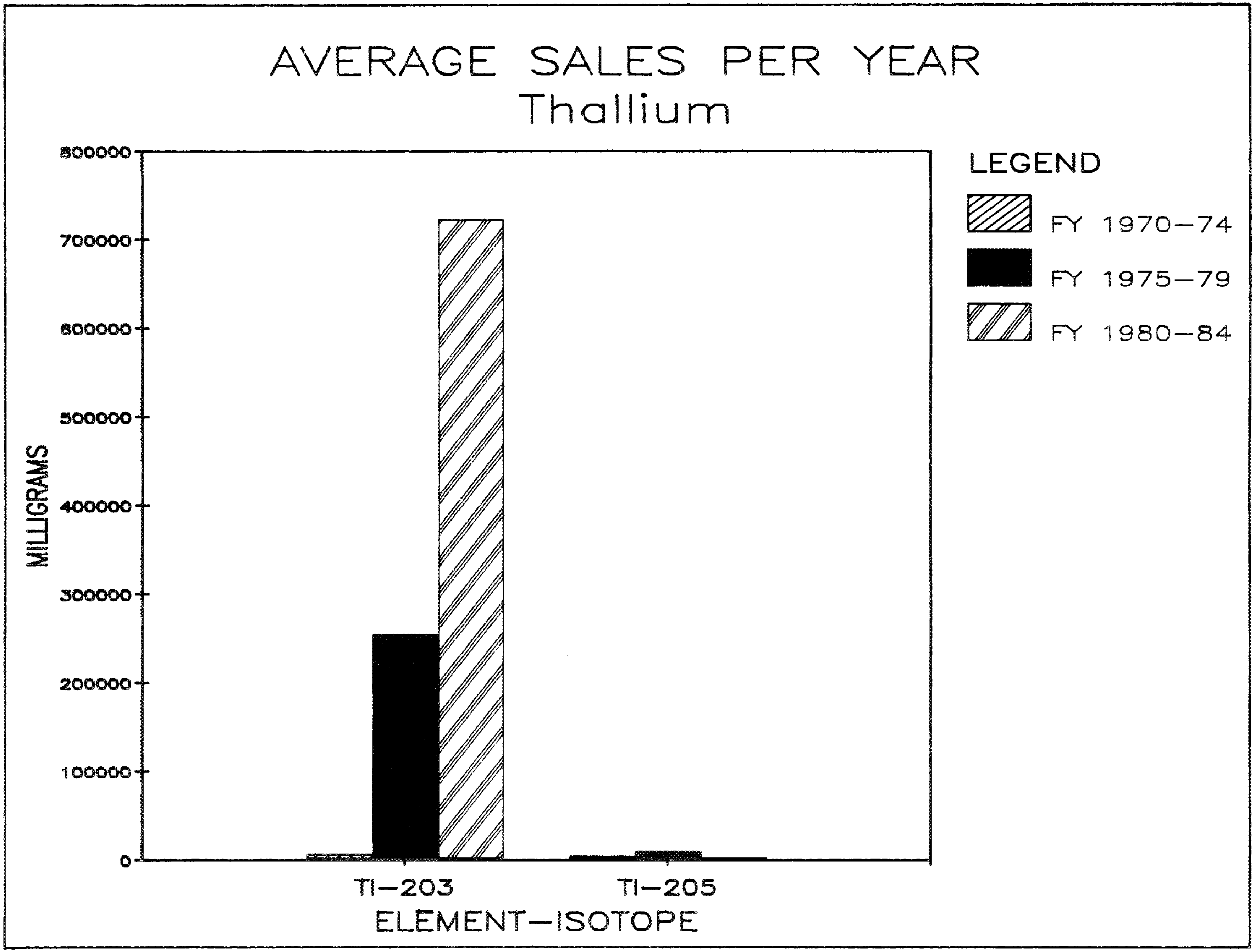
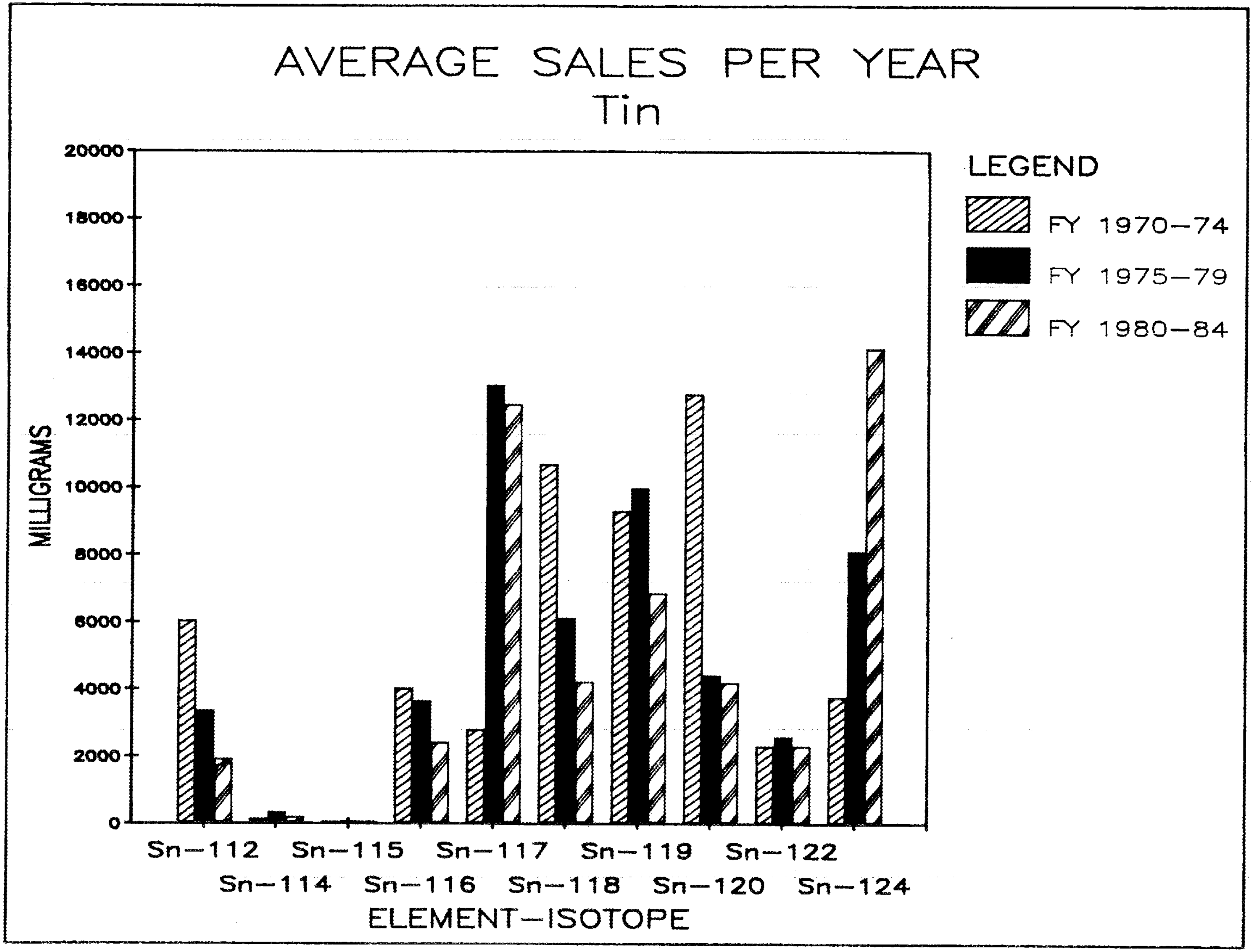
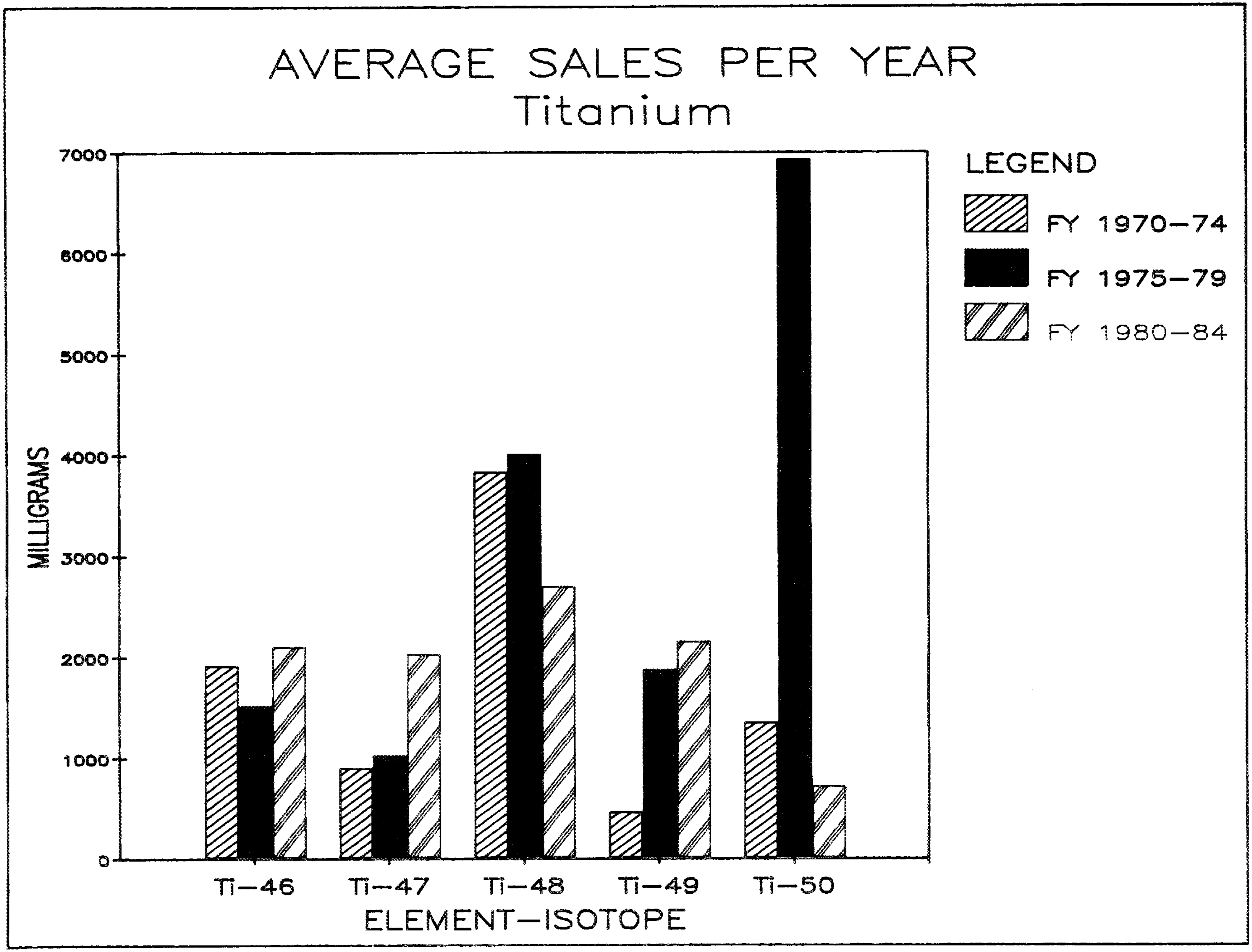
800
1000
1200
1400
1600
1800
2000
S-32
S-33
S-34
S-36
ELEMENT-ISOTOPE

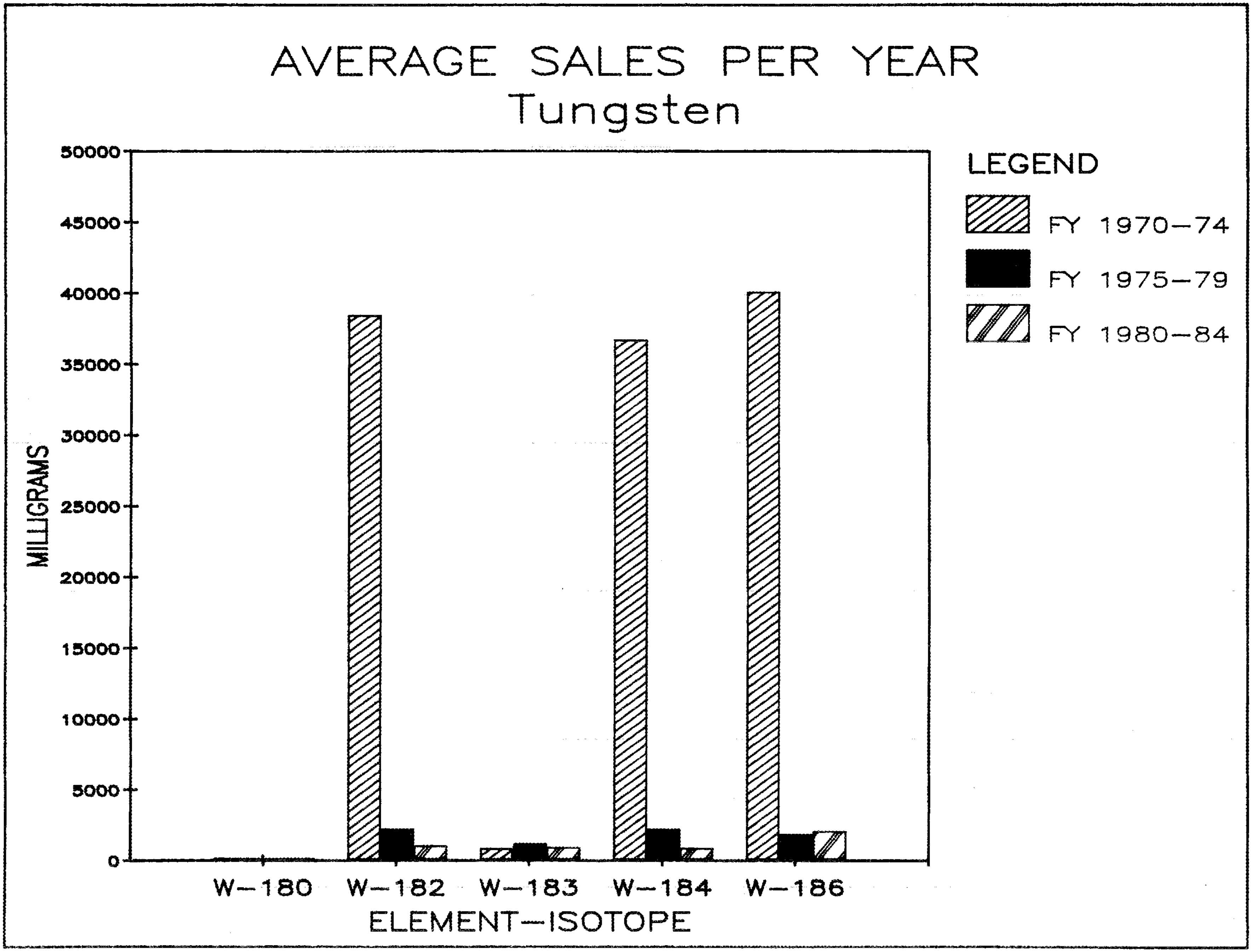

AVERAGE SALES PER YEAR
Tantalum
MILLIGRAMS
0
1
2
3
4
5
6
7
8
9
Ta-180
Ta-181
ELEMENT-ISOTOPE
LEGEND
FY 1970-74
FY 1975-79
FY 1980-84

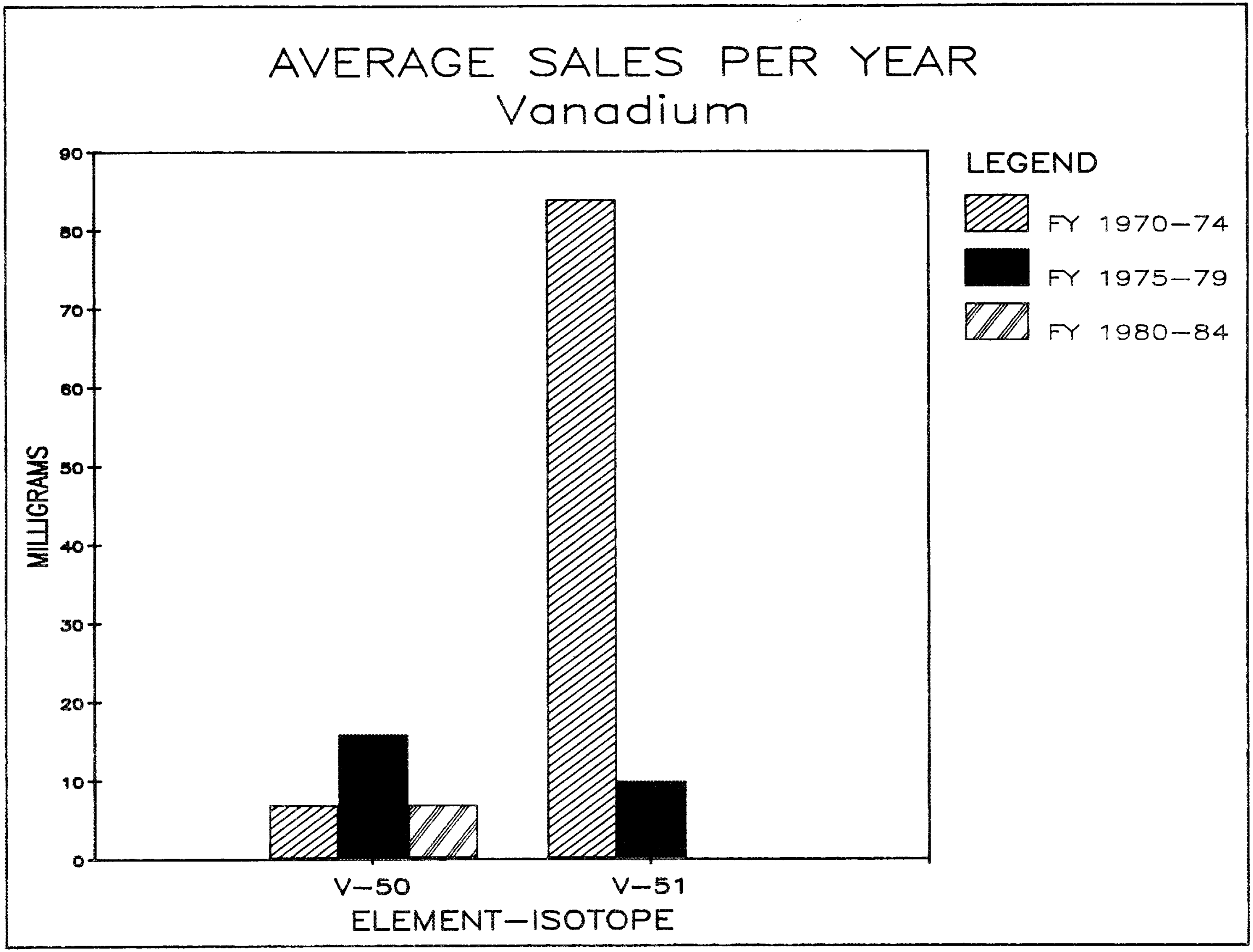

AVERAGE SALES PER YEAR
Tellurium
LEGEND
FY 1970-74
FY 1975-79
FY 1980-84
MILLIGRAMS
40000
35000
30000
25000
20000
15000
10000
5000
0
Te-120
Te-122
Te-123
Te-124
Te-125
Te-126
Te-128
Te-130
ELEMENT-ISOTOPE

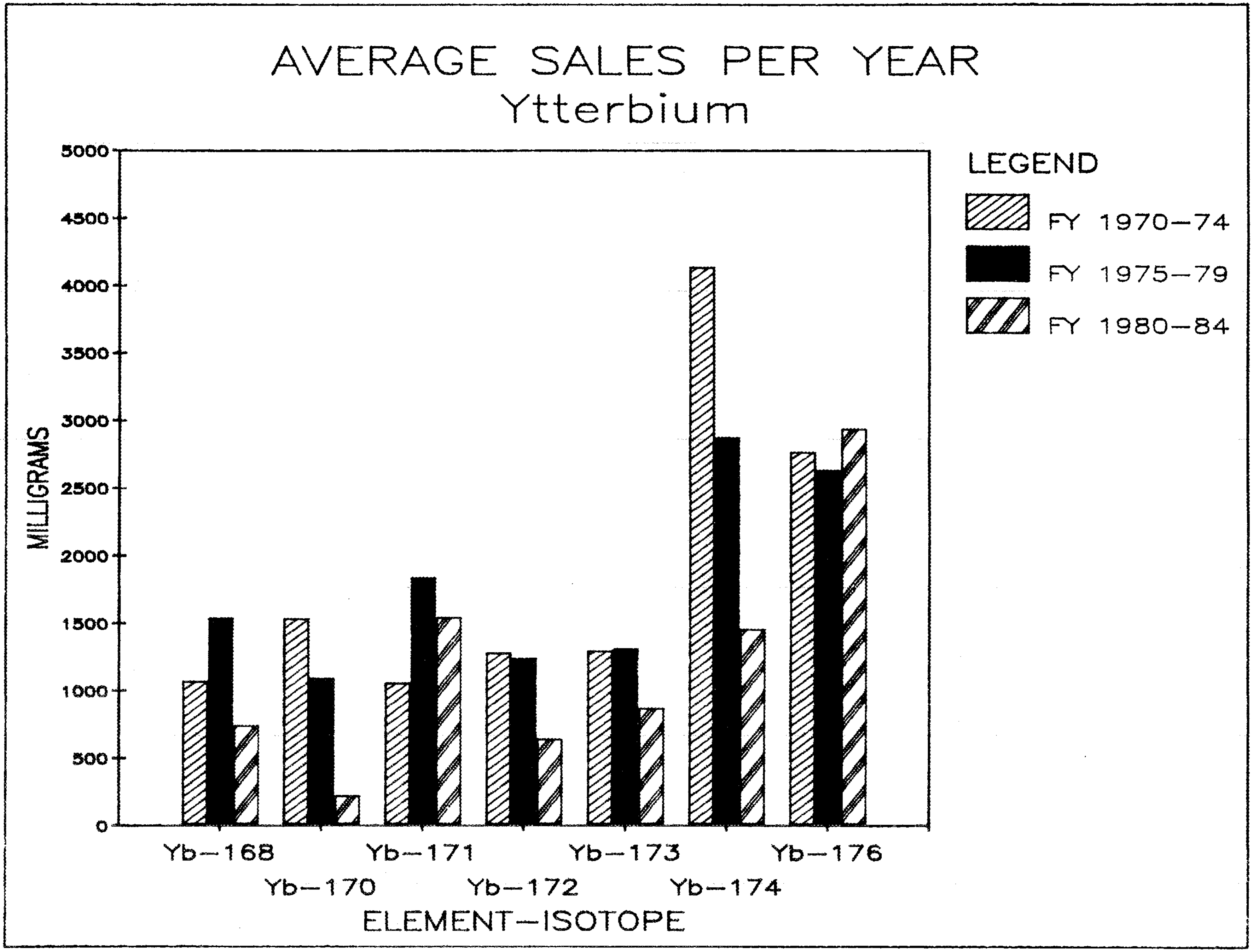

AVERAGE SALES PER YEAR
Thallium
MILLIGRAMS
800000
700000
600000
500000
400000
300000
200000
100000
0
Tl-203
Tl-205
ELEMENT-ISOTOPE
LEGEND
FY 1970-74
FY 1975-79
FY 1980-84

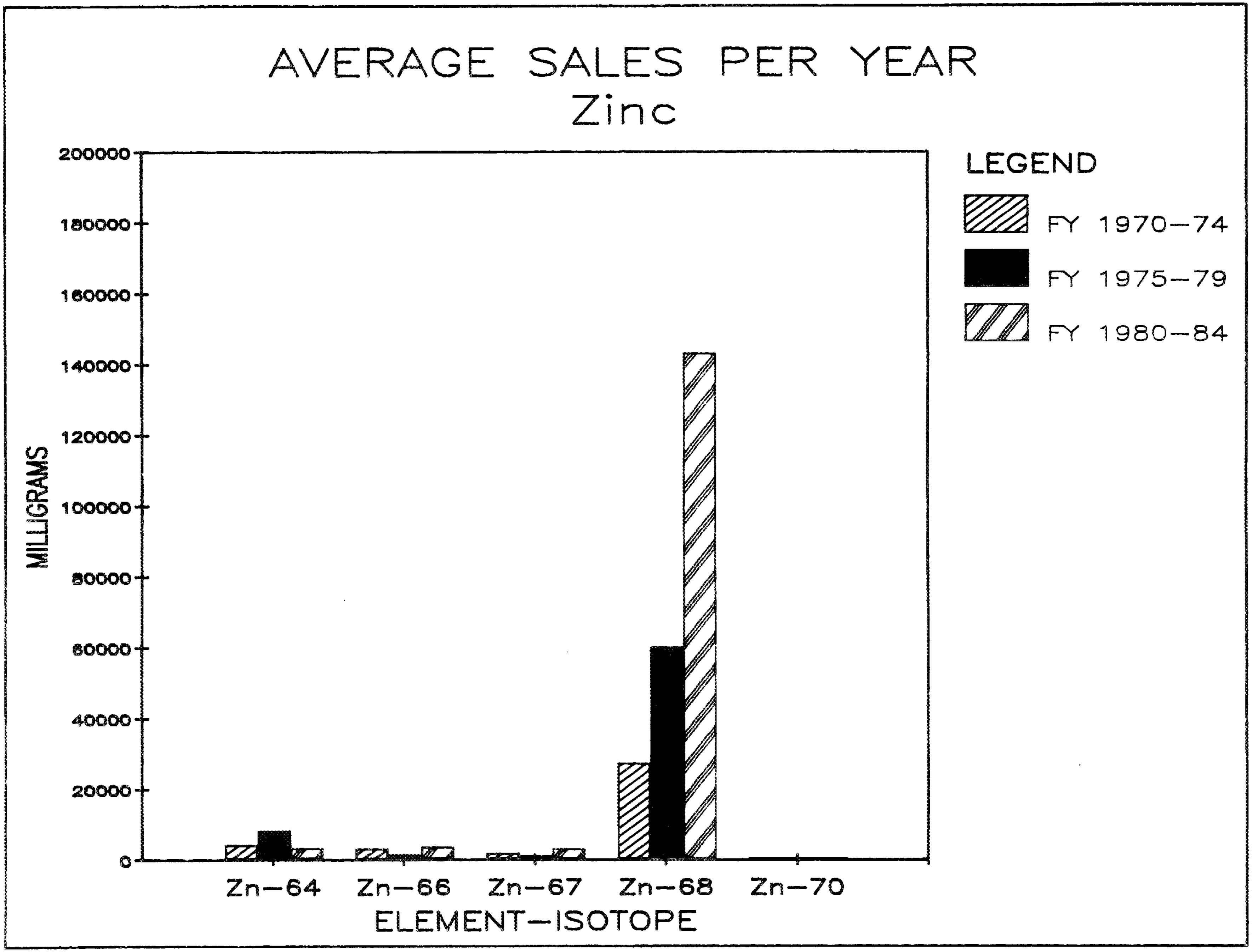

AVERAGE SALES PER YEAR
Tin
LEGEND
FY 1970–74
FY 1975–79
FY 1980–84
MILLIGRAMS
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
Sn–112
Sn–114
Sn–115
Sn–116
Sn–117
Sn–118
Sn–119
Sn–120
Sn–122
Sn–124
ELEMENT–ISOTOPE


AVERAGE SALES PER YEAR
Titanium
LEGEND
FY 1970-74
FY 1975-79
FY 1980-84
MILLIGRAMS
7000
6000
5000
4000
3000
2000
1000
0
Ti-46
Ti-47
Ti-48
Ti-49
Ti-50
ELEMENT-ISOTOPE

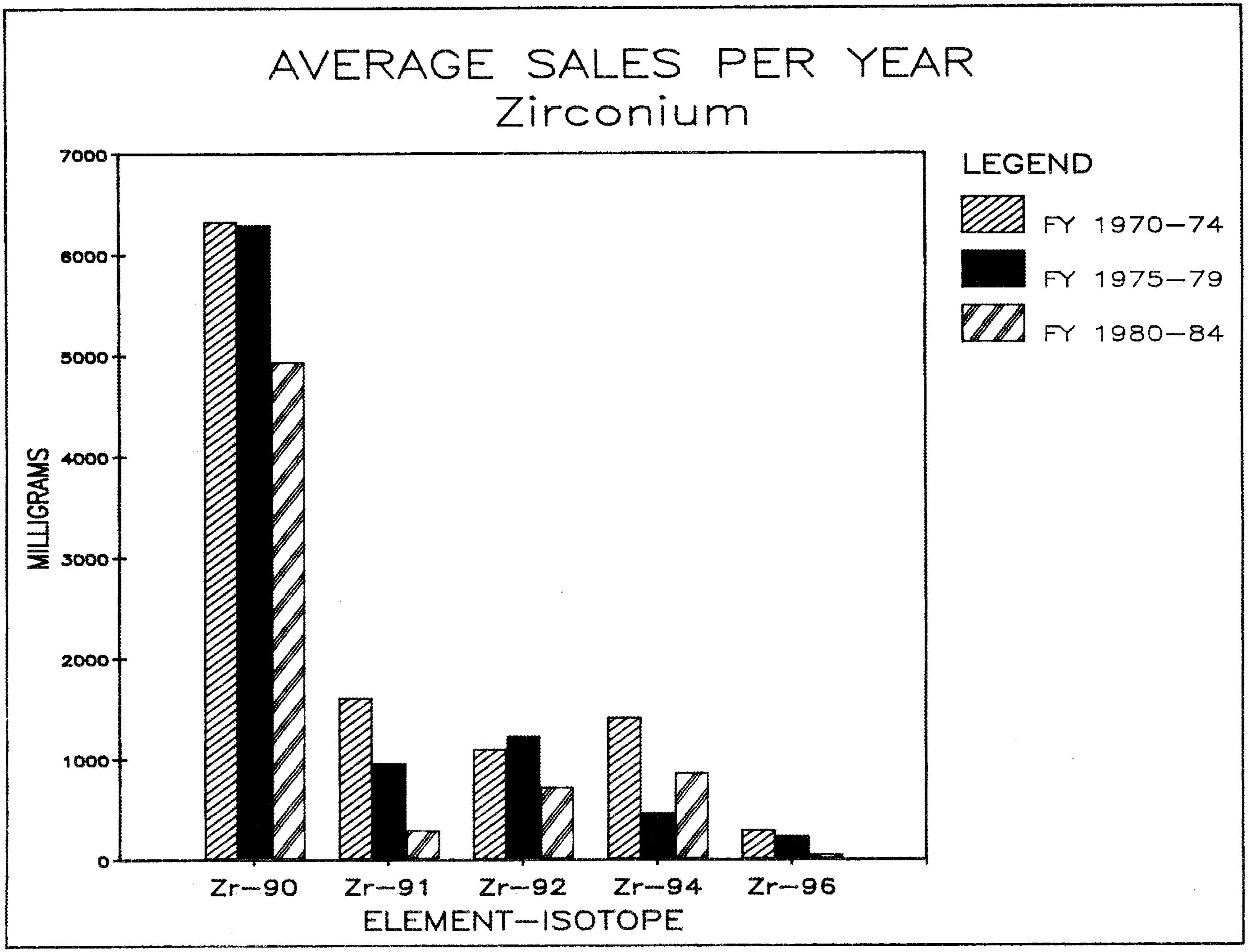

AVERAGE SALES PER YEAR
Tungsten
LEGEND
FY 1970–74
FY 1975–79
FY 1980–84
MILLIGRAMS
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
W–180
W–182
W–183
W–184
W–186
ELEMENT–ISOTOPE


AVERAGE SALES PER YEAR
Vanadium
LEGEND
FY 1970-74
FY 1975-79
FY 1980-84
MILLIGRAMS
0
10
20
30
40
50
60
70
80
90
V-50
V-51
ELEMENT-ISOTOPE


AVERAGE SALES PER YEAR
Ytterbium
LEGEND
FY 1970-74
FY 1975-79
FY 1980-84
MILLIGRAMS
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
Yb-168
Yb-170
Yb-171
Yb-172
Yb-173
Yb-174
Yb-176
ELEMENT-ISOTOPE


AVERAGE SALES PER YEAR
Zinc
LEGEND
FY 1970-74
FY 1975-79
FY 1980-84
MILLIGRAMS
200000
180000
160000
140000
120000
100000
80000
60000
40000
20000
0
Zn-64
Zn-66
Zn-67
Zn-68
Zn-70
ELEMENT-ISOTOPE

154


AVERAGE SALES PER YEAR
Zirconium
MILLIGRAMS
7000
6000
5000
4000
3000
2000
1000
0
Zr-90
Zr-91
Zr-92
Zr-94
Zr-96
ELEMENT-ISOTOPE
LEGEND
FY 1970-74
FY 1975-79
FY 1980-84

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